

UNIVERSITY OF BRISTOL



THE ANNUAL REPORT

OF THE

Agricultural and Horticultural
Research Station

(THE NATIONAL FRUIT AND CIDER INSTITUTE)

LONG ASHTON, BRISTOL
1945

BATH:

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Miss M. C. D. MUNRO, B.Sc. (Hort.) (Lond.), Ph.D. (Glasgow), Dip. Hort. (Swanley), Advisory Officer. (*Appointed 21/3/45.*)

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	E. J. HEWITT, B.Sc. (Hons.) (Lond.), A.K.C., Agricultural Research Council Plant Nutrition Scheme.
	D. J. D. NICHOLAS, B.Sc. (Hons.) (Lond.), A.K.C., Agricultural Research Council Plant Nutrition Scheme.
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INTRODUCTION.

By T. WALLACE, M.C., D.Sc., F.R.I.C., Director.

The year 1945 has been notable as marking the beginning of the change-over from special war-time activities to a normal peace-time programme of work. In some respects, especially in the fruit plantations, the changes must of necessity be gradual, as new experiments must be planned and land and materials specially prepared.

Nor will the new programme merely mean the resumption of the 1939 investigations along old lines, for there is a need to reorientate viewpoints on old problems and new problems also await attack. The transition seems likely to be seriously impeded by losses in staff, arising from the reorganisation of Government schemes for research and advisory services and the competition of industrial firms for trained scientists. During 1945, Long Ashton lost three senior members of staff in this way, and it is probable that further losses will occur in 1946. In research institutes of the character of Long Ashton the work of the senior scientific officers is highly specialised and some time must elapse before a new appointee can make his full contribution to the research team.

During the year the Department has lost by death two very old friends, Sir Stanley Badock and Mr. John Ettle.

Sir Stanley, who was Pro-Chancellor of the University and Chairman of Council at the time of his death in December, 1945, had been a member of the Agricultural Committee since 1923 and had also been closely connected with the work of all three centres of the Department during his long period of service as Treasurer of the University. He was keenly interested in agriculture, being a well-known breeder of Gloucester Old Spot pigs, and was a familiar figure at Long Ashton Institute gatherings.

The death of John Ettle last March has severed one of the few remaining links with the establishment of The National Fruit and Cider Institute and the earliest years of its work at Long Ashton. At that time, in his official position as Horticultural Instructor on the staff of the Agricultural Education Department of the Somerset County Council, he was responsible for the educational and experimental activities of that body in the County. It was a natural development that, in view of his extensive knowledge of cider fruit and orchards in that county and in Gloucestershire, an arrangement was reached at the outset with the Somerset authority under which his services were made available by the inclusion of the superintendence of the nursery, orchard, and plantation work at Long Ashton as part of his duties. In that capacity he was largely responsible for the planning and general course of the outdoor work there until the termination of his County appointment twelve years later. A good judge of cider himself and with a lifetime's contact with cider making, his advice and experience in that direction also proved very helpful during the most critical years of the Institute. After his official connection with it ceased, his keen personal interest in its progress was maintained unbroken to the end of his life. It, indeed, owes much to him for his part in establishing its foundations and, fittingly, the original trial cider orchard adjoining its entrance and largely planned by him, still promises to stand for many years to come as a tribute to his labours and as a reminder of one who served it well and disinterestedly.

Accommodation has continued to be a serious problem both at Long Ashton and the Berkeley Square centre, and the Ministry of Agriculture has intimated that, because of labour shortage, it may not be possible to build additional laboratories at Long Ashton for some time to come. This will seriously hamper developments proposed in Plant Pathology, and it is to be hoped that the extensions will not be too long delayed. Some slight relief will result in October, 1946, from the departure from Long Ashton, under the new National Agricultural Advisory Service, of the Advisers in Mycology and Entomology, which should free three rooms in the main laboratory building. There is also an urgent need for a change in the canteen arrangements. The canteen has proved very popular with all sections of the staff and under present conditions is indispensable to their well-being. Usually between 50 and 60 lunches are served daily. These large numbers result in overcrowding and discomfort, and often there is a tendency to overflow into the library, which is an undesirable occurrence. The Ministry of Agriculture has been approached to see whether it can help by the provision of a surplus Services hutment which could be used for canteen purposes.

The fruit crop at Long Ashton in 1945 was very seriously affected by the abnormally severe frosts which occurred on the nights of April 29th and 30th. At the time of the frosts there was an unusually heavy set of all tree fruits and the destruction to these was almost complete, only a few bushels being harvested off the farm. The bush fruits, of which the acreage is relatively small, were not so severely damaged and approximately half a crop was obtained. The losses will seriously affect the financial position of the Station, which during recent years had been satisfactory.

The loss of the crop naturally affected some of the field experiments, and it was particularly disappointing that crops on the young bush cider trees, which promised to be heavy for the first time, were almost completely destroyed. Advantage was, however, taken of the frost effect to see whether growth-promoting chemicals could produce a crop from frosted fruitlets. The effects, though considerable, were not large enough to be of use in practical fruit growing, but the results have opened up a promising line of investigation.

The general character of the research work carried out during the year showed little change from that in 1944, though there was one important innovation in the field programme—a trial to test the effectiveness of D.D.T. washes against aphids on apple trees. The cropping results were nullified by frost, but the effects on the pest indicated that a commercial control may be possible by D.D.T. sprays.

On the advisory side the volume of work was again very large and the actual number of enquiries showed a slight increase. Further progress was made in the development of the National Milk Testing and Advisory Scheme, which already gives promise of increasing the interest of farmers in the bacteriological quality of milk.

During the year the principle of a National Agricultural Advisory Service was accepted by the Government and the first steps were taken in the re-organisation by the transfer of Advisory Economics Sections from the existing Advisory Centres to University Departments from October 1st, 1945. In the Bristol and Seale Hayne Provinces the Economics Sections became part of the Department of Economics of Bristol University, and under this arrangement the Bristol Section no longer forms part of the Berkeley Square Centre.

The Provincial Advisory Conference has continued to function as reported

in the previous report, but in addition a meeting of the full Conference was held on September 6th, 1945.

The Committee on Land Classification has now completed land classification maps for the three counties of Gloucester, Somerset and Wiltshire, and these are now available for reference in the University. It is proposed to publish, in the near future, the map of the Region comprising the three counties on a scale of $\frac{1}{4}$ " to the mile together with a memoir.

Apart from the losses incurred as the result of frost damage to the crops in the Long Ashton plantations, financial provision has been satisfactory and has allowed of very full programmes of research and advisory work. It is also gratifying to report the continued increase in the membership scheme of the Long Ashton Institute, and thanks are due to the older members who have helped in this connection.

The articles appearing later in the report, unlike the reports issued during the war, have been contributed solely by the staff at Long Ashton. This change has been made at this time because of pressure on space and the impending detachment of the Berkeley Square Centre in September, 1946.

BRISTOL ADVISORY CENTRE.

The statistics for the advisory work which are given later in the report (page 227) show that the general volume of the work was well maintained during the year.

A further change in the administration of the centre was necessitated by the resignation of Dr. R. Stewart, Advisory Chemist, from August 31st, 1945, to take up the appointment of Professor of Agricultural Chemistry at the West of Scotland College of Agriculture. Dr. Stewart had acted as deputy to Mr. Ling in charge of the Berkeley Square Centre, and under that arrangement the work had run very smoothly. Dr. Stewart's departure was a great loss to the Department, where during the short period he had been on the staff, he had done much useful work and had become a very popular colleague.

On the departure of Dr. Stewart, Mr. Menzies, Head of the Veterinary Section, took over the administrative duties, and Mr. J. O. Jones was appointed to the post of Advisory Chemist from September 1st.

The thanks of the Department are due to Mr. Menzies for filling the administrative vacancy in addition to carrying on with his Veterinary work. Under his guidance work has proceeded smoothly and without a break at a very difficult transition period.

The appointment of Mr. Jones to the post of Advisory Chemist was a very happy one since he had been on the staff at Long Ashton for many years previously and was already very familiar with the main problems of crop husbandry within the Province, whilst, coming from a farming family, he has also a good knowledge of stock.

Apart from the transfer to the Agricultural Economics Section to the Economics Department of the University from October 1st, 1945, the most notable feature of the work at Berkeley Square has been the continued expansion of the National Milk Testing and Advisory Scheme.

The area milk laboratories are now able to relieve the central laboratory of many advisory problems which can be dealt with locally though it has not been possible so far to equip them for the chemical testing of milk.

Staff.

A list of Staff changes is given on page 228. Of these the most important among the senior staff have been referred to above. Of the remainder the

transfer of Miss Bottomley to Seale Hayne College requires mention. Miss Bottomley was employed as a fieldman for special surveys of fertiliser practice in the five counties of the Province. On completion of the work she was transferred to continue with similar work in Devon and Cornwall.

Buildings.

The unsatisfactory state of accommodation at Berkeley Square, following the large war-time expansion of the staffs in the various sections, has been referred to in previous reports. Little can be done to improve conditions at present, especially in view of the transfer of the work from the Centre under the National Agricultural Advisory Service from October 1st, 1946.

Thanks are due to the Staff for the excellent work they have done under very trying conditions, and it is sincerely to be hoped that the new service will be able to provide accommodation in keeping with the high standard of work which has been a feature of the Centre.

After long negotiations and delays work has at last been started on the new Field Laboratory at Evesham, and it is hoped that the building will be ready for use during the summer of 1946. This laboratory should prove a most valuable sub-station for the new Advisory Service and should ensure that the intensive horticultural industries in the surrounding area are well served.

LONG ASHTON RESEARCH STATION.

Staff.

During the year the Station lost three senior members of its Staff, Dr. T. Swarbrick, Pomologist; Mr. J. O. Jones, Chemist; and Dr. R. L. Wain, Organic Chemist.

Dr. Swarbrick had been associated with the Institute for many years. He came first as a graduate student from the University of Leeds in 1925, and after spending one year at the Station he proceeded to the U.S.A. to undergo further training in Pomology under Professor R. H. Roberts, at Wisconsin. On his return in 1927 he was appointed Research Pomologist at Long Ashton and from 1930 to 1938 he also served as Plantations Officer. From 1938 he again filled the post of Research Pomologist, though during the war he undertook investigations on crops other than the hardy fruits, in particular on tomatoes and potatoes. Dr. Swarbrick was a very lively colleague, always full of novel ideas and helpful in assisting others with their problems. He made many notable contributions to Pomology, particularly in connection with rootstock problems, and tree shaping and pruning, and, more latterly, in the use of growth-promoting substances. He left Long Ashton to take up a commercial appointment with Messrs. Shell Mex, and we wish him every success in his new work.

The departure of Mr. J. O. Jones is another great break with the past. He also joined the Staff in 1927 and for the greater part of his time was concerned with chemical problems in relation to the storage qualities of fruits. In later years he was also closely connected with studies in fruit tree nutrition, and during the war he played a leading part in the Station's investigations on mineral deficiencies of agricultural and horticultural crops. Like Dr. Swarbrick, "J.O." was a very popular member of Staff, and the good wishes of all his old colleagues go with him in his new appointment. We are happy to record that in his new work at the Berkeley Square Centre we are still able to collaborate closely with him in problems of crop husbandry.

Dr. R. L. Wain first joined the Staff at Long Ashton from Wye College

in 1939 to undertake work on copper and sulphur fungicides. He was transferred to the Graded Staff of the Station in 1943, in which capacity he was responsible for investigations in Organic Chemistry in the Plant Pathology team. During his stay at Long Ashton, Dr. Wain made some notable contributions to his subject and his resignation, to return to Wye College to take up the post of Head of the Chemistry Department, inevitably made a serious break in the chemical work. His new appointment should offer him scope for his wide chemical knowledge and his liking for teaching, and we hope he will be happy in his new work.

The Station has been fortunate in filling the three senior vacancies referred to above by officers with considerable experience in their respective subjects.

The post of Pomologist was filled by Dr. L. C. Luckwill, an old Bristol graduate, whose most recent appointment had been as Assistant Lecturer in Botany in the University of Aberdeen. During the war Dr. Luckwill was engaged in statistical work in the Ministry of Aircraft Production. His previous botanical work had been in connection with the Genetics and Physiology of the Tomato.

Mr. C. Bould was appointed to succeed Mr. J. O. Jones. Mr. Bould is a graduate in Horticulture of Reading University who, since graduating, has had experience in Plant Nutrition and Soil Surveys, and more recently in connection with the utilisation of town wastes and sewage sludges and the making of composts from these materials. His training and experience are well suited for the investigations in fruit nutrition he will undertake at Long Ashton.

Dr. Wain has been succeeded by Dr. D. Woodcock, who received his undergraduate and graduate training at King's College, Newcastle, in the University of Durham. During the war Dr. Woodcock was engaged in problems of Organic Chemistry for the Ministry of Supply, under Prof. R. D. Howarth, F.R.S., at Sheffield University. Dr. Woodcock's experience should fit him well to develop the work begun by Dr. Wain.

Other appointments which have been made during the year are as follows:—

Miss M. Sturdy, as Assistant to Instructress in Domestic Fruit and Vegetable Preservation from 1/2/45 to replace Mrs. M. Croxall.

Mr. W. R. Stanton, as Field Survey Officer under the Agricultural Research Council Mineral Deficiencies Scheme from 24/3/45, and transferred to Pomology to succeed Mr. P. T. H. Pickford from 1/8/45.

Mr. A. Stringer, as Research Assistant, Entomology, under special Agricultural Research Council grant for Insecticidal Bio-assays from 13/7/45.

Mr. A. C. Bunt, as Research Assistant, under a special Ministry of Agriculture grant in aid of construction of self-propelled atomiser.

We are also happy to record the return of Mr. R. M. Jarrett, Pomological Recorder on December 10th, 1945, from service in the R.A.F., in which he had served as a Leading Aircraftsman since January, 1940.

During the year Mr. G. T. Spinks was granted sick leave from 12th February to 3rd August, 1945.

Buildings and Land.

There has been no change in the serious position regarding laboratory and office accommodation at Long Ashton. The departure of the Advisory Officers in Entomology and Mycology in September, 1946, will do a little to ease the overcrowding, but conditions will remain unsatisfactory until

the proposed laboratory extensions can be undertaken. Unfortunately there appears little hope of proceeding with these new buildings for some considerable time and thus the prospects of developing the post-war research programme as we should hope to do are not bright.

Moreover, as previously reported, there is an urgent need for alterations and extensions in the cider house buildings, whilst, on the farm, buildings of all kinds have become inadequate to supply current needs. In particular, attention must be drawn to the urgent need of fruit storage accommodation, since the war period has witnessed the coming into bearing of many acres of tree fruits, and it will be impossible with present facilities to store the crops in a satisfactory way for proper marketing.

The extra storage capacity is also essential for many of the investigations on tree fruits which necessitate estimates of crop characters. Attempts to ease accommodation problems on the farm will be made by acquiring hutments and shedding from Government sources should these become available.

Housing accommodation for new members of staff is a great anxiety and is especially difficult and unsettling for those with families. The Station houses are fully occupied and during the year further alterations were made in Fenswood Farm House, in the section vacated by Mr. Pickford, in order to house two families instead of one. It is difficult to see how further help can be provided at present in this most urgent problem, but it is hoped that everything possible will be done to ease the situation at the first opportunity.

During the year estimates have been obtained for repairs of roads and for painting and repairing of outbuildings and greenhouses, many of which are now in very urgent need of attention. It is hoped that some of the most pressing work will be carried out during the summer of 1946.

Thanks are again due to Dr. Kearns for his continued help in the maintenance of property, machinery and implements.

Mr. J. H. Butler has continued his tenancy of the outlying portions of the Station farm.

In the plantations, preparations for the gradual change over to the post-war programme have begun. New fruit plots have been planned and nursery work has been begun to prepare the necessary trees for the new plots.

Certain of the pre-war manurial plots which have been used for more general investigations in plant nutrition during the war are being retained for this purpose at present pending decisions on the final requirements of this work.

Good progress has also been made in replanning and replanting the willow beds, with the aid of a special grant from the Agricultural Research Council for this purpose.

At the present time, while there is a shortage of fruit planting material, the Station is raising special stocks of black currants and loganberries, and of the former the new Station variety, Mendip Cross, is being propagated in quantity. In 1945 the Station also raised, on behalf of the Ministry of Agriculture and in co-operation with the Horticultural Trades Association, quantities of seedling rootstocks of apple, cherry and plum. The actual numbers distributed under the scheme were as follows :—Apple, 8,000 ; cherry (Mazzard), 22,600 ; plum (Myrobolan), 17,150.

In connection with work on Diseases of Hops now in progress small plots of Hops have been established in the plantations to study special points. The area, in all, is less than one acre but it may be expected that this will expand slightly in future.

The failure of the tree fruit crops in 1945 provided an opportunity for carrying out estate work on the farm which had fallen in arrears during the war years and for improving cultural conditions on several of the plots. As a result, conditions in the plantations are now very satisfactory excepting where work cannot be undertaken due to lack of materials. Fencing and wiring against vermin present the most difficult problems in repair work.

Although the cider fruit crop throughout the West Country orcharding area was small in 1945, suitable supplies of fruit were obtained for work in the Cider House and to allow of a full programme of research. As in 1944, the labour staff in the Cider House was supplemented by Italian prisoners of war during the cider making season.

Research Activities.

In spite of staff changes it was possible to carry out a very full programme of research work in 1945.

Good progress was made in studies relating to mineral deficiencies. In pot cultures refined techniques for the study of trace elements were further improved by the use of pre-treatments for pots, sand and water, and the development of methods for purifying chemicals. Boron and iron deficiencies were successfully produced in a number of plants and a very successful experiment was made to determine the factors responsible for injurious effects in acid soils. It was shown that manganese toxicity is a very important factor under such conditions. The experiments also demonstrated the value of the pot culture method for the study of such problems.

The tissue test method for the rapid chemical determination of mineral deficiencies was further studied. Several of the chemical standards were given numerical values and detailed investigations were made to determine the relationships between the various stages of growth of plants and tissue test values. A field outfit, suitable for hard wear and tear and for making chemical tests under field conditions, was designed in conjunction with Messrs. The Tintometer, Salisbury.

Further large scale experiments on tomatoes confirmed that severe magnesium deficiency can be completely remedied by means of three to five applications of a magnesium sulphate spray (2% Epsom Salts plus spreader) given at intervals of three weeks and beginning shortly after planting. A good commercial control was also obtained by a soil dressing at planting of Epsom Salts at 1 ton per acre. The spray technique requires less than 5 cwt. of Epsom Salts per acre, but is less convenient than the soil dressing. Spraying with magnesium sulphate (2% Epsom Salts) also appears useful as a control for magnesium deficiency in apples, though at present six foliage sprays during the season have been used for complete control.

Rotational experiments on vegetable crops (including potatoes) have brought out interesting points in connection with the manurial needs of these crops. Important points shown have been that stable manure is too low in nitrogen for many vegetable crops and that the continued use of inorganic fertilisers of the N.P.K. type may result in acute deficiency of magnesium. This deficiency is also shown to be induced by high potassium (as sulphate) and by low nitrogen levels of manuring.

Notable advances were made in the use of growth-promoting chemicals in relation to the parthenocarpic development of tomatoes and apples. Naphthoxyacetic acid at 30 p.p.m. was used successfully on tomato plants to "set" bottom trusses which had failed due to unfavourable conditions. The

chemical could be applied three weeks after the failure to set had occurred. Parthenocarpic tomato fruits were also produced by the use of crude ether extracts of tomato flowers and by synthetic oestrogens, in particular, Stilbestrol.

On apple fruitlets, in which the embryos had been killed by frost, it was possible, by means of a mixed spray of growth-promoting chemicals, to prevent fruit drop and partially to swell the fruits of the variety Miller's Seedling, although the treatment was ineffective in Cox Orange Pippin. The experiments suggest means by which many difficult problems of pollination may be approached.

In connexion with the raising of seedling stocks of apple, plum and cherry, methods were developed for the pre-treatment of the seeds to effect rapid germination. By cold storage treatment of the seeds, regulating both temperature and moisture conditions, it has been possible to ensure germination in about a fortnight after spring sowing in the open field.

Entomological work on specific pests included the introduction of soil treatment for the control of pear midge, the ground under the trees being soaked with 3% tar oil emulsion at the rate of 1,000 galls. per acre. Similar soil treatment has given promising results against currant midge. On apples, red spider remains one of the most difficult pests to control. The winter petroleum wash does not kill more than 85% of the winter eggs, so must be supplemented by an exceptionally well-applied petal fall wash either of petroleum oil or of lime sulphur plus adequate wetter. In farm orchards successive winter washing with D.N.C.-petroleum alone allows the building up of red spider infestation and the increase of apple sucker attack.

Field trials on fungus diseases of fruit showed that black currant leaf spot was controllable by a Fermate spray applied before picking. The same material used on apples was less damaging than lime sulphur but inferior in fungicidal value.

Critical laboratory tests showed that D.N.C. was readily reduced by certain emulsifiers and supplements and also in the presence of iron undergoing corrosion. As the reduction products are non-toxic to eggs of sucker, winter moth and red spider, special precautions in packaging the stock emulsions are necessary.

Specifications and methods of analysis are in preparation for D.N.C.-petroleum emulsions, formaldehyde and metaldehyde: those for tar-petroleum winter washes, nicotine and nicotine sulphate have recently been accepted.

In investigations of synthetic insecticides, the toxicity of D.D.T. and allied compounds was found to parallel their ability to lose hydrochloric acid. In a field trial on apples a single application of D.D.T. at the early pink bud stage was highly successful in eradicating an established aphid infestation.

At the request of the Ministry of Agriculture, a tractor-drawn and driven spray outfit with ancillary components was designed specially for contract work. The prototype was assembled at Long Ashton and approved by the Ministry who have now ordered 50 of these machines. Testing and standardization of pest control machinery and accessories has been continued.

During the past two years it has been possible to carry out cider making trials with fruits from trial bush cider plantations established about 10 years ago. The cropping of the trees has been of a similar order to those of free cropping dessert and culinary sorts and the ciders made have been of high quality. Even at this early stage it may be said that, so far as cider quality is concerned, the method is entirely satisfactory. The economics of the

system from the growers' viewpoint will be more clear when the trials in the Long Ashton plantations are more advanced.

In laboratory investigations interesting observations have been made of the failure of acetification to occur, under favourable conditions, in samples of ciders made from the bush plantations apples.

Serious outbreaks of "ropiness" and "sickness" have occurred in ciders during the past two seasons and the organisms associated with the disorders have been isolated and are under examination.

Further experiments have been made relative to the stability of ascorbic acid in black currant syrups and to the presence of substances which interfere with its estimation in such products. It has been shown that in bottled products stability depends largely on the amount of oxygen in the head space and that stable conditions are ensured by small head space and treatment with SO_2 .

A survey of the ascorbic acid content of English apple varieties has been commenced and preliminary estimations in certain cider varieties have shown that some of these have high contents and may prove a satisfactory source of the vitamin. Detailed studies have also been made of factors affecting the ascorbic acid content of tomatoes, including growth conditions and position of the fruits on the plants. Further experiments with potatoes have confirmed previous results that in the "blackening" of boiled potatoes, variety and site characters are of more importance than manuring. Potash manuring may alleviate blackening, but in several acute instances the effects have been relatively small. Attempts to overcome blackening by cooking methods have shown that some control may be effected by cooking with acids (*e.g.* acetic acid) either alone or with SO_2 . The treatments affect flavour and this point must be considered in applying the treatments.

Special attention has also been given to the effects of various home methods used in preserving fruits and vegetables on the Vitamin C and riboflavin contents.

Investigations on Hop Diseases in the West Midlands hop growing area were begun in 1943 in collaboration with the East Malling Research Station. Surveys of the more serious diseases have been made and experimental treatments begun on them. In 1945, the scope of the work was increased to include nutritional and entomological work, and there is now a small team of workers engaged on various aspects of the main problems.

Annual Field Day. The Annual Field Day for members was again combined with the Annual Meetings of the Governors and Members of the National Fruit and Cider Institute. The function took place on July 20th, at which time there was much of interest to see in the Station plantations. Among those present was His Grace the Duke of Beaufort, who was making his first visit to the Station.

Visitors. The numbers of organised parties and visitors received at the Station must have constituted a record for all time. A full list is appended and of these the following require special note :—

4 parties of French scientists.

Agricultural Improvement Council Agricultural Machinery Improvement Board.

Agricultural Research Council Plant Pathology Survey Group.

2 visits from American University students, Shrivensham.

Loveday Committee on Higher Agricultural Education.

Horticultural Education Association Annual Meetings.

Agricultural Research Council Entomology Survey Group.

It was particularly pleasing to be able to welcome small scientific parties

and individual scientists from France and Holland and to re-establish relationships with their respective Institutions. The Institute was able to help them both by discussions and by giving them copies of the Station reports for the war years.

Agricultural Improvement Council
 Agricultural Machinery Improvement Board.
 Agricultural Research Council Entomology Survey Group.
 Agricultural Research Council Plant Pathology Survey Group.
 American University Students, Shrivenham, Berks (2).
 Army Education Course.
 Association of Scientific Workers and British Association of Chemists.
 A.T.S. Army Blood Supply Depot (2).
 Bassaleg and District Young Farmers' Club.
 Botanical Students, University College of Wales.
 Botany Department, Birmingham.
 Bristol Adult School Union.
 Bristol Branch of Pharmaceutical Society.
 Bristol Co-operative Society Youth Department.
 Bristol Motor Company.
 Bristol University Botanical Society.
 Burnham-on-Sea Allotment and Garden Association.
 Canadian Services Leave Course.
 Cardiff and District Gardeners' Association.
 Chartered Surveyors' Institution.
 Cheltenham Horticultural Discussion Group.
 Chew Valley Young Farmers' Club.
 Clifton College Young Farmers' Group.
 Crewkerne Branch Young Farmers' Club.
 Dominions and United States Forces (Cannington Course).
 Dorset Growers.
 Educational School of A.A. Command (3).
 Educational and Vocational Training—Air Force.
 No. 3 Formation Army College.
 French Fruit Growing Specialists.
 French Scientific Mission to United Kingdom (3).
 "Grasshoppers."
 Ham Green Training Centre.
 Horticultural Education Association Annual Meetings.
 6th Regiment Maritime R.A.
 Merchant Venturers' Technical College Pharmacy Students' Association.
 Ministry of Food Advice Centre Students.
 Ministry of Food Cereals Division.
 National Co-operative Men's Guild.
 Reading University Students (2).
 Royal Artillery, 489 (M) H.A.A. Battery.
 Somerset National Farmers' Union.
 Tyntesfield Hospital (American Soldiers).
 Upton-on-Severn and District Young Farmers' Club.
 Western Branch of Y.M.C.A.
 Weston Gardeners and Food Production Association.
 Wiltshire Growers.
 Wiltshire Secondary School Headmasters.
 Worcestershire Teachers.
 Youth Group.

Shows, Demonstrations, etc. Although these have not been resumed on the pre-war basis, there has been much activity in connection with "Grow-more" campaigns, and the Institute has helped in many ways, by providing exhibits, demonstrations and speakers at Conferences. The following list indicates the scope of these activities :—

Bath Spring Show, Pump Room, Bath. Pests and Diseases of Brassicas.
Teachers' Refresher Course. Taunton School. Vegetable Diseases Exhibit.
Cheltenham Spring Show. Pests and Diseases of Brassicas.
Cirencester Dig for Victory Show. Pests and Diseases of Brassicas.
Potato Demonstration. Broome Manor, Swindon. Potato Diseases.
Hereford Dig for Victory Show. Pests and Diseases of Brassicas.
Worcestershire W. A. E. C. Potato Demonstration at Springhill, Fladbury. Diseases and Pests of Brassicae.

Worcestershire W. A. E. C. Machinery Demonstration, Bromsgrove. Diseases and Pests of Brassicae.

Worcestershire County Council Demonstration Orchard, Knightwick. Diseases and Pests of Fruit Trees.

Worcestershire W. A. E. C. Outdoor Tomato Variety Plot, Badsey. Diseases of Outdoor Tomatoes.

Malvern Horticultural Show. Winter Gardens, Malvern. Diseases of Horticultural Crops.

Bristol Horticultural Show, Drill Hall. Fruit, Fruit Preservation, Diseases and Pests of Brassicae.

Cheltenham Autumn Show. Mineral Deficiencies in Celery. Gold Medal awarded for Exhibit.

Bath Horticultural Committee Autumn Show. Pests and Diseases of Brassicae.

Hallen, Henbury and District Agricultural Discussion Society. "Take-all," Potato Blight and Brassicae Pests.

Research Students and Voluntary Workers. It has not been possible, so far, to continue the pre-war practice of providing graduate courses for higher degrees, and this will be very difficult until more laboratory accommodation is available. Nevertheless, several scientific workers have worked for short periods at the Station, and in addition several short courses of instruction in spraying machinery were given.

As usual Miss Crang provided courses of instruction in Home Preservation Methods.

Details of these various activities are as follows :—

Mr. John Bowden, B.Sc., rendered very valuable assistance to Dr. Miles during the summer vacation in connection with investigations on the control of root flies.

Miss Joan Smith, a student in Natural Sciences at Oxford University, and Miss M. J. Mence, a student in Natural Sciences at Cambridge University, each spent a fortnight in Mr. Ogilvie's laboratory to obtain some practical experience in applied mycology.

Lt. T. Anstey, of the Department of Extension, Khaki University of Canada, spent two months at the Station, and during that period assisted the staff engaged in work on mineral deficiencies.

Courses of instruction were given in the use and maintenance of spraying machinery. These included one week's course for spray teams, a course for mechanics and a course in acid spraying technique. Seventeen War Agricultural Executive Committees sent representatives to these courses.

Facilities were provided at Long Ashton to the Shell Film Unit for the preparation of an instructional film entitled "How to Spray."

The following representatives of cider firms received instruction in cider making during the year :—

Mr. M. V. Rowling (Messrs. R. N. Coate & Co., Ltd., Nailsea, Som.).

Mr. E. R. O. Heaton (Messrs. P. H. Tonkin, Ltd., Truro, Cornwall).

Mr. F. Grigg (The Creedy Valley Cider Co., Crediton, Devon).

A total of 99 students attended courses arranged in Domestic Preservation of Fruit and Vegetables during the spring and summer. In addition to the usual three fortnightly courses, two shorter courses in judging preserved produce were arranged.

It is a pleasant duty to record once more the valuable help accorded in the plantations by Mr. H. E. Beviss, who has done much to ensure continuity in recording work during the war years.

Acknowledgments. It is gratifying to report the continued help and co-operation of numerous growers, industrial firms and other organisations during the year.

The methods of assistance and collaboration are as usual very varied.

In particular, a number of growers in the Evesham and Pershore areas have again placed plots at the disposal of the Station for experiments on vegetable manuring. Messrs. S. Byrd and Sons, Evesham, have continued to make available to the Department, without payment, the site of the Evesham Field Laboratory. The facilities provided by this laboratory have been of immense value to horticulturists in the West Midlands and to the Department throughout the war period, and the thanks of all are due to Messrs. Byrd for their help.

Several firms have once more aided the work of the Station by financial grants and by the provision of materials for experiments. All forms of help given have contributed to the success attained in the year's work and sincere thanks are due to all who have so willingly co-operated.

The special thanks of the Director are due to the scientific staff who have again worked at high pressure under congested conditions in the laboratories. In addition to their scientific work many have helped considerably in voluntary capacities. Dr. Martin has assisted generally with scientific problems, and Dr. Kearns with buildings and machinery; Mr. Marsh has carried out the main editorial duties and has been responsible for organising many of the parties who have visited the Station; Miss Crang and Miss Sturdy have continued to shoulder the heavy work of supervising the canteen. Mr. Spinks has continued to act as Librarian and during the period of his illness the duties were undertaken by Miss Kieser. As Plantations Officer, the usual heavy burden of work has fallen on Mr. Hobbis, who has endeavoured to provide all with field facilities for their experiments.

All other grades of staff have co-operated loyally and willingly in a very heavy programme of work, and a particular word of thanks is due to the working staffs in the laboratories, office, plantations and cider house, who have contributed materially to the success of the experimental work.

TRIALS OF CLONAL APPLE ROOTSTOCKS SELECTED FROM "FREE" AND "CRAB" SEEDLINGS.

III. PERFORMANCE ON A NUMBER OF SITES IN THE WEST OF ENGLAND WHEN WORKED WITH SEVERAL SCION VARIETIES.

By G. T. SPINKS.

INTRODUCTION.

The origin of this series of clonal apple rootstocks was described in 1930 (2).

In 1940 T. N. Hoblyn (1) published an account of a trial at East Malling which included these stocks worked with the variety Lane's Prince Albert. At the same time the present author published the results (3) of several trials carried out at Long Ashton in which the scion varieties Worcester Pearmain, James Grieve, Lane's Prince Albert, Newton Wonder and Blenheim Orange were used.

The present paper deals with the results of the trials at Long Ashton for a further six years, in addition to the period already covered. It also deals with the results obtained from a number of trial plots established in various parts of the West of England. These plots included the same range of rootstocks, some of the scion varieties named above and several other scion varieties in addition. When the rootstocks were originally selected it was thought that some of the clones would be suitable for the growth of standard trees and a number of the trials at Long Ashton and at other centres therefore included this type of tree.

EXPERIMENTAL DATA.

In the account of the various trials given below, each trial has been given a number and each plot is identified by a number or code letter. In some cases the plot includes only one scion variety, the trees of which constitute one trial. Trees of another variety were interplanted to act as pollinators where necessary but are not regarded as part of the trial and are not mentioned in the records.

In other cases a plot contains two or more scion varieties, each row consisting of one variety only, but the trees of different varieties are regarded as constituting separate trials and are considered independently.

In almost every trial the plot was divided into two halves and a unit of trees on each rootstock was randomised in each half. The unit usually consisted of four or five trees, planted in line. Where a plot contained more than one scion variety the randomising of the varieties was done independently. Where any other lay-out was adopted this is mentioned in the description of the trial.

The trees were grown in bush form except where stated to be standards. Some of the standard trees were grown under grass orchard conditions and where this occurred the fact is mentioned in the description of the trial.

Trees on the East Malling rootstocks II and XII were included in almost all the trials for purposes of comparison. These two rootstocks are designated EM II and EM XII, respectively, throughout this paper.

The dates and ages shown in the tables below refer to the time at which

the trees were planted in the trial plot. The actual age of the tree from the time of working in the nursery is stated in the description of each trial.

The plots at Long Ashton, the material used in them, the treatment they received, and the records obtained from them, have already been described (3).

The other trials were carried out on the land of various fruit growers and farmers. Many of the plots containing standard trees were designed to test the performance of the rootstocks under the conditions usually occurring when trees of this type are grown in farm orchards and the sites were selected with the object of providing trials under various conditions of soil and other natural factors. The trees required to plant the plots as planned were grown at Long Ashton and delivered to the sites when of a suitable age for planting. The growers planted the trees and from that time onwards were entirely responsible for their culture and management, though advice was supplied from Long Ashton when requested or when it seemed necessary. The author visited the plots usually twice a year, at blossom time and when the fruit was ready for picking, in order to observe and record the performance of the trees.

The recording of data on the plots has presented a serious problem, especially as the trees grew larger and came into bearing. At first, measurements of height, spread of branches and trunk diameter (at 1 ft. above ground level), were taken, but later only the trunks were measured. The amount of blossom was noted, but no counts were made.

When the trees were young the number of fruits on each tree was counted and the crop was weighed when picked. In many of the trials the commencement of the bearing of appreciable crops coincided with the outbreak of war and during the war it was impossible to record the crops with the accuracy desired. No counts of fruit were made. Even at Long Ashton in one or two years it was impracticable to weigh the fruit from each tree and crop weights were obtained by counting the number of boxes of fruit picked from each tree. In other cases the weight of fruit from a unit, but not from individual trees, was obtained, while sometimes the crop weight was simply estimated by an inspection of each individual tree. In some years no figures of any kind were obtained from some of the trials.

Under these conditions it cannot be claimed that the figures for some of the plots are either accurate or complete and it therefore seems useless to attempt an analysis in order to show the statistical significance of the figures submitted. In the following tables, therefore, only the mean figures of the data available are shown.

The trials are described in the following sections of this paper, the trials for each scion variety being dealt with in separate sections, *e.g.* Worcester Pearmain. The data obtained are set out at the end of the sub-section dealing with each trial.

Worcester Pearmain.

1*. Plot 16; Long Ashton.

Two-year-old bush trees on 13 rootstocks were planted in December 1926. Eight trees on each stock were completely randomised as single tree units.

Site is practically level. The soil is derived from Keuper Marl and belongs to the Shallow Worcester Series. The surface soil is a non-calcareous, fine, sandy loam and it overlies a sandy compact clay. Drainage is poor and the land often lies wet. Drought conditions are liable to occur in summer.

* Trial number.

The ground was kept under clean cultivation until 1936, when a grass mixture was sown.

Management has been good but manuring has been restricted during the war years.

TABLE I.
WORCESTER PEARMAIN, BUSHES, 1926-1944.
PLOT 16.

Rootstock	Mean total crop per tree (kg.) for 18 years	Rootstock	Mean trunk diam. (cm.) at 18 years
EM II	186.9	EM XII	17.4
EM XII	185.9	B 2	14.9
E 7	171.0	G 8	14.7
E 8	165.2	EM II	13.7
G 8	164.8	A 3	13.6
F 12	150.5	F 12	13.5
A 8	136.0	E 7	13.3
A 3	119.5	E 8	12.4
B 2	119.3	A 8	12.0
F 2	69.2	F 2	11.5
A 9	45.4	A 9	9.6

2. Plot W; Gloucestershire.

Three-year-old trees on six rootstocks were planted in February 1930. On each stock there were two units, each consisting of four trees.

The site slopes slightly to the east and is almost at the bottom of a hollow running south to north. The soil is a fine sandy loam derived from the Pennant Grit of the Coal Measures, but heavy loam is present at a depth of 18 inches. During the course of the trial it was found that drainage was poor and that water-logging frequently occurred.

Intercrops of vegetables have been grown. Management has been poor, pruning and spraying having been neglected. The trees have suffered from aphid, sawfly, scab and canker.

Records are very incomplete, especially since 1940, but crops are known to have been consistently poor.

Mean trunk diameters in 1944 (15 years):—

A 3	B 2	E 8	F 12	D 1	A 10
12.2	12.2	12.0	9.3	9.2	9.1 cm.

3. Plot K; Worcestershire.

Three-year-old bush trees on 17 rootstocks were planted in December 1930. There were two units of five trees on each stock. (Only one unit of five trees was available for each of the stocks A 8, A 9, E 7 and F 2).

The site is almost level and the soil is a heavy loam of the Badsey Series, derived from the Middle Lias and Oolite formations. Below 18 inches the

subsoil consists of gravel which is water-bearing, making the plot liable to water-logging.

The ground was kept under clean cultivation, with some intercrops of small fruit and vegetables until 1939, when it was grassed down. Management was fairly good.

Most of the trees made good growth for a few years, but by 1937 canker was beginning to be serious and by 1940 the disease had become so bad that it was obvious that the plot was of no further use either as a trial or for commercial purposes. This prevalence of canker is ascribed to the water-bearing character of the subsoil.

The crop records for the plot are very poor, as they include the frost years of 1935 and 1938 and the period when the trees were being increasingly crippled by canker. In 1940 the crop was so poor that no records were made.

TABLE II.
WORCESTER PEARMAN, BUSHES, 1930-1940.
PLOT K.

Rootstock	Mean total crop per tree (kg.) for 10 years	Rootstock	Mean trunk diam. (cm.) at 10 years
E 7	11.4	E 7	10.1
G 7	10.8	EM XII	9.4
G 8	9.5	F 2	9.2
EM II	8.4	G 8	9.2
F 2	6.6	EM II	8.7
G 6	6.3	G 7	8.5
E 8	6.0	B 2	8.4
A 8	5.9	F 11	8.3
A 10	5.9	F 10	8.2
F 10	5.5	E 8	8.1
EM XII	5.4	G 6	8.0
F 11	5.1	A 3	7.6
A 3	4.2	A 8	7.3
F 12	4.2	A 10	7.2
A 9	3.2	D 1	6.9
B 2	3.0	F 12	6.8
D 1	2.8	A 9	6.5

4. Plot T; Worcestershire.

Three-year-old bush trees on 10 rootstocks were planted in December 1930. Two units of five trees on each stock were planted.

The site is about half-way up a hill with a gentle slope to the north and the soil is a medium loam probably of the Bridgnorth Series, derived from Keuper Sandstone. Drainage is fairly free.

The plot has been kept under clean cultivation throughout the trial. Management has been very good, the trees have made excellent growth and since they came into bearing crops have been regular and abundant.

In 1940 a count of the fruits on each tree was made and in 1941 the number of fruits was estimated, approximate figures for the crop weights then being obtained by calculation. In all other years the crop was weighed—in the earlier years from individual trees, but from 1942 to 1944 from the unit of five trees taken together.

TABLE III.
WORCESTER PEARMAN, BUSHES, 1930-1944.
PLOT T.

Rootstock	Mean total crop per tree (kg.) for 14 years	Rootstock	Mean trunk diam. (cm.) at 14 years
F 11	307.5	EM XII	15.1
EM XII	300.5	A 3	13.9
G 7	295.4	F 11	13.6
E 7	270.5	E 7	13.6
EM II	255.5	G 7	13.4
G 8	235.5	EM II	13.0
A 3	213.9	G 8	12.2
G 6	187.3	G 6	11.7
F 12	107.8	A 10	10.9
A 10	83.7	F 12	9.6

5. *Plot E; Devonshire.*

Four-year-old bush trees on 11 rootstocks were planted in December 1931. Two units of four trees on each stock were planted. (Only one unit of four trees was available on stocks G 8 and EM II.)

The site slopes gently to the west and the soil is typical of that which is widespread in Devonshire, being a medium shaley loam containing quartz fragments. Shale is found at depth of 15 or 18 inches. There was no sign of impeded drainage.

The plot was kept under clean cultivation throughout the trial and management was good. Unfortunately this is another instance of local conditions rendering the trees very susceptible to canker, the decisive factor in this case being the heavy rainfall of 40 inches a year, and after a good start the trees became so heavily infected that it was decided to grub them before they had borne any appreciable crops. The crop records therefore represent only two years of cropping. There was no opportunity to measure the trunk diameters when the trial was discontinued in 1938 and the figures for this measurement were obtained in 1934, when the trees had just got established.

6. *Plot P; Wiltshire.*

Two-year-old bush trees on nine rootstocks were planted in December 1934. Two units of five trees on each stock were planted.

The site is almost level, bordered by rising ground to the north. The

TABLE IV.
WORCESTER PEARMAN, BUSHES, 1931-1937.
PLOT E.

Rootstock	Mean total crop per tree (kg.) for 6 years	Rootstock	Mean trunk diam. (cm.) at 3 years
EM II	5.9	EM XII	5.1
F 11	5.5	G 8	4.2
E 7	4.0	G 7	3.9
G 8	3.8	EM II	3.9
F 10	3.4	A 3	3.7
G 7	3.2	B 2	3.7
A 3	3.0	E 7	3.7
F 12	3.0	F 11	3.4
G 6	2.5	G 6	3.4
EM XII	2.3	F 10	3.3
B 2	1.7	F 12	3.2

soil is a light sandy loam typical of the Upper Greensand formation, very deep and apparently well drained.

The plot was clean cultivated. Management was fairly good, but there were difficulties created by local conditions. There was serious disturbance to the plot, first by the laying of a drain and secondly by the digging of air-raid trenches in it. There were difficulties about spraying the trees and records of the small crops which were borne were rather unreliable owing to the amount of fruit pilfering which took place. War-time conditions accentuated these difficulties and it was decided to discontinue the trial in 1940. By this date ten trees were rather badly cankered, and it appeared possible that this trouble might become general throughout the plot.

The trees were not old enough to have borne any appreciable crop, but the largest crops had been obtained from the trees on EM II (30 fruits per tree) and E 7 (26 fruits).

Rootstock E 7 had produced the largest trees (trunk, diam. 8.3 cm.), A 3 and F 11 both gave diameters of 7.8 cm., whilst the trees on the rest of the stocks measured from 7.5 to 7.1 cm. This trial did not include the very vigorous stock EM XII.

7. Plot 21; Long Ashton (Standards).

Four-year-old standard trees on six rootstocks were planted in December 1928. Two units of five trees on each stock were planted. In the case of stock E 7 only one unit of four trees was planted and the trees were five years old. All the trees in this trial were worked low in the nursery in the usual way, and thus the trunks of the trees consisted of the scion variety. All standard trees mentioned in this paper were produced by this method except where it is stated that any other procedure was followed.

The site is open and slopes gently from north to south. The soil is derived from colluvial material of mixed origin, including Millstone Grit,

Carboniferous Limestone and some Keuper Marl. The surface soil, a calcareous, heavy sand containing a fair amount of fine sand, is fairly uniform but increases in depth towards the lower end of the plot. The subsoil is similar except for a decrease in calcium carbonate and an increase in clay. In several places large stones were found when digging holes for planting. Drainage is free.

The ground has been kept under clean cultivation and an intercrop of black currants was grown from 1929 to 1936, followed by green crops for two years and again by black currants until 1944. Moderate spring dressings of mixed fertilizer have been applied annually and pruning has consisted of thinning the heads as usually practised on standard trees.

TABLE V.
WORCESTER PEARMAN, STANDARDS, 1928-1944.
PLOT 21.

Rootstock	Mean total crop per tree (kg.) for 16 years	Rootstock	Mean trunk diam. (cm.) at 16 years
EM XII	193.6	EM XII	16.9
E 7	121.3	F 10	11.4
F 10	99.8	E 7	11.3
G 7	62.2	G 7	10.6
F 11	56.6	F 11	9.6
D 1	36.8	D 1	8.8

8. Plot 22; Long Ashton (Standards).

Two-year-old standard trees on eight rootstocks were planted in December 1928. Two units of four trees on each stock were planted.

The site adjoins Plot 21 and is similar as regards soil and aspect, but it is an old pasture and has been kept as a grass orchard since the trees were planted. The grass has been grazed and the trees have received normal good treatment for standards as regards pruning and spraying.

TABLE VI.
WORCESTER PEARMAN, STANDARDS, 1928-1944.
PLOT 22.

Rootstock	Mean total crop per tree (kg.) for 16 years	Rootstock	Mean trunk diam. (cm.) at 16 years
G 8	95.4	G 8	12.4
E 7	90.6	E 7	12.2
F 11	89.8	F 11	11.9
G 7	76.9	F 2	11.6
F 10	63.2	F 10	11.6
G 6	60.3	G 7	11.4
F 2	40.4	G 6	9.9

9. Plot 22; Long Ashton (Standards).

Another set of standard trees was planted in Plot 22 at the same time as those mentioned in the previous section, but as they were older trees they are here considered separately.

Five-year-old trees on five rootstocks were planted in December 1928. There was one unit of five trees on each stock.

TABLE VII.
WORCESTER PEARMAN, STANDARDS, 1928-1944.
PLOT 22.

Rootstock	Mean total crop per tree (kg.) for 16 years	Rootstock	Mean trunk diam. (cm.) at 16 years
E 7	137.9	G 7	14.2
G 8	125.2	G 8	12.8
G 7	123.9	E 7	12.6
G 6	75.7	G 6	11.9
F 12	33.1	F 12	11.1

10. Plot EA; Worcestershire (Standards).

Five-year-old standard trees on five rootstocks were planted in December 1928. There was one unit of five trees in line on each stock.

The site is fairly open with a slight slope to the south-east and is probably on the junction of the Old Red Sandstone and Carboniferous formations. The soil is mainly of the Eardiston Series, with a variable depth of reddish fine sandy light loam over soft purplish-red micaceous rock. Heavier soil of the Bromyard Series may be present in places.

The trees were planted in an old pasture and form an extension of a previously planted young grass orchard. They have received the normal treatment of a grass orchard and management has been good.

Owing to war-time conditions very few records have been obtained since the trees started cropping well. In 1944, with the exception of five trees on various stocks which had suffered severe checks from canker or injuries to the trunk, all the trees were healthy and carrying good crops.

From the scanty data available, the order of crop yield appears to be as follows :—

G 8, E 7, G 7, F 12, G 6

E 7 and G 7 yielded about 70% of the crop of G 8, while F 12 and G 6 produced only about 40%.

As regards the size of the trees, the trunk diameters in 1944 were in the following order, E 7 having the largest measurement :—

E 7, G 8, F 12, G 7, G 6

James Grieve.

11. Plot 16; Long Ashton.

The trees in this trial occupied the same plot of ground as those dealt with in Trial 1, rows of James Grieve alternating with rows of Worcester Pearmain.

Two-year-old bush trees on eleven rootstocks were planted in December 1926. Single tree units were randomised over the plot.

Canker spread very rapidly from about 1934 onwards, many trees had to be grubbed by 1937 and the trial was then discontinued.

TABLE VIII.
JAMES GRIEVE, BUSHES, 1926-1937.
PLOT 16.

Rootstock	Mean total crop per tree (kg.) for 11 years	Rootstock	Mean trunk diam. (cm.) at 11 years
EM II	95.5	EM II	13.1
E 8	77.9	A 3	12.7
E 7	74.4	A 9	12.4
A 3	70.6	A 8	12.3
F 2	57.1	B 2	12.2
A 9	53.7	E 8	12.0
A 8	53.2	E 7	11.9
F 12	51.0	F 2	11.6
B 2	49.6	F 12	10.5
A 10	14.0	A 10	9.3
D 1	11.0	D 1	6.3

12. *Plot O; Worcestershire.*

Three-year-old bush trees on six rootstocks were planted in January 1930. Two units of five trees on each stock was planted.

The site slopes very gently to the south and is at an altitude of about 700 ft. The soil is of the Sherborne Series, a brown heavy loam with many fragments of limestone derived from the yellowish rock of the Inferior Oolite which occurs at a depth of about 18 inches. Drainage is free.

By 1935 the trees had made very little growth and were being increasingly damaged by canker. It was evident that the situation was unsuitable for the growing of apples of this variety and the trial was discontinued.

The following rootstocks were included in the plot :—

A 3, A 10, B 2, D 1, E. 8, F 12

Crops for the six years of the trial were very small, the total per tree ranging from 1.4 to 3.2 kg. There was very little difference in the trunk diameters of the trees.

The trial is considered to have provided no useful information about the rootstocks used.

Laxton's Superb.

13. *Plot O; Worcestershire.*

Two-year-old bush trees on 17 rootstocks were planted in December 1930. There were two units of five trees on each stock.

The site adjoins that described in Trial 12 and all the conditions were

similar. Management was fairly good, but a number of trees suffered from severe injuries to the trunks by cultivating implements and also on two occasions when sheep got into the plantation.

On the whole, the trees did not grow well. Some were quite good but others showed leaf-scorch or pale foliage and stunted growth. By the end of 1935 it was decided to grub all the trees on the lower part of the plot, comprising about threequarters of the whole trial, as so many poor trees were included in that section. Records from this part of the plot therefore extended over five years only and yielded little information. On the rest of the plot observations were made until 1938 but were then discontinued.

In the first five years of the trial the heaviest crop was borne by trees on rootstock G 7, closely followed by those in E 7 and E 8, the crops being 5.5, 5.2 and 4.4 kg. respectively (EM II was not represented in the trial). Trees on EM XII were among the poorest croppers up to that time (1.2 kg.) but were the largest in size: E 7 had also produced fairly large trees.

After 1935 only five stocks were represented in the remains of the trial: figures for crop weights and trunk diameter up to the end of 1938 are given in Table IX.

TABLE IX.
LAXTON'S SUPERB, BUSHES, 1930-1938.
PLOT 0.

Rootstock	Mean total crop per tree (kg.) for 8 years	Rootstock	Mean trunk diam. (cm.) at 8 years
E 7	27.9	EM XII	10.1
E 8	16.9	E 7	6.2
F 11	14.0	F 2	5.9
F 2	8.4	F 11	5.1
EM XII	7.3	E 8	5.0

Lane's Prince Albert.

14. Plot 16; Long Ashton.

Three-year-old trees on 16 rootstocks were planted in March 1929. There were two units, each including four trees, on each stock.

The site adjoins that on which the Worcester Pearmain and James Grieve in Trials 1 and 11 were grown, and the conditions and management were similar in every way. The trees have probably suffered from insufficient dressings of fertilizers during the war years.

Cox's Orange Pippin.

15. Plot L P; Herefordshire.

Two-year-old bush trees on 15 rootstocks were planted in February 1936. Stocks A 3, A 8, A 9, A 10, E 7 and F 10 were each represented by a single unit of six trees, but there were two units of six trees on each of the other nine stocks.

The site is open, with a gentle slope to the east. The soil is of the Ross and Tanyard series with variations between a deep coarse sandy light loam and a similar loam overlying heavy loam or clay at variable depths. In some places heavy loam or clay appears at the surface.

TABLE X.
LANE'S PRINCE ALBERT, BUSHES, 1929-1944.
PLOT 16.

Rootstock	Mean total crop per tree (kg.) for 16 years	Rootstock	Mean trunk diam. (cm.) at 16 years
EM II	184.3	EM II	13.0
G 7	123.2	E 7	12.3
E 7	106.1	EM XII	12.1
EM XII	96.8	G 7	11.9
G 8	93.0	A 9	11.6
F 10	90.3	F 10	11.4
G 6	86.3	G 8	11.2
B 2	83.5	G 6	10.7
A 8	79.6	B 2	10.6
A 3	77.7	A 8	10.2
F 11	73.3	F 12	10.0
E 8	65.9	A 3	9.3
A 9	55.8	E 8	9.2
F 12	47.3	F 11	8.9
A 10	36.9	D 1	8.9
D 1	36.6	A 10	8.8

The plot has been clean cultivated except that strawberries were grown in the alleys for a few years. Management has been good.

During the course of the trial it has become evident that the local variations in the soil on the plot have caused a very uneven performance of the trees on any one rootstock. Trees on all the stocks have shown this irregularity in growth and cropping.

By 1940 it was evident that the trees on A 10 and one unit of trees on each of the stocks F 12 and G 6 would never make satisfactory growth and they were grubbed.

The total crop figures given in the following table do not include the crop for 1942, as it was found impossible to obtain any records in that year.

Bramley's Seedling.

16. Plot 21 ; Long Ashton (Standards).

This trial was designed to compare the performance of trees on one clonal stock, G 8, with that of trees on two series of seedling stocks.

Standard trees were planted in December 1928. There were three units, each including five trees of G 8, on different parts of the plot, the trees being four years old when planted. Four units, each containing five three-year-old trees on seedlings of Hampshire Crab were planted, and three rows, each

TABLE XI.
COX'S ORANGE PIPPIN, BUSHES, 1936-1944.
PLOT LP.

Rootstock	Mean total crop per tree (kg.) for 9 years	Rootstock	Mean trunk diam. (cm.) at 9 years
EM II	44.5	EM XII	9.3
G 7	42.3	A 3	9.1
E 7	41.5	E 7	8.8
E 8	40.5	A 8	8.7
A 8	38.2	B 2	8.4
A 3	26.1	EM II	8.4
G 8	23.9	E 8	8.2
EM XII	23.9	G 7	7.9
A 9	23.8	G 8	7.9
B 2	19.1	A 9	7.3
F 11	18.9	F 12	7.2
F 12	13.7	F 11	7.0
G 6	11.6	G 6	6.3
F 10	10.0	F 10	6.2

extending the length of the plot, contained 44 trees on seedlings of mixed origin.

The site is the same as that described under Trial 7 (Worcester Pearmain Standards) and conditions and treatment were similar.

TABLE XII.
BRAMLEY'S SEEDLING, STANDARDS, 1928-1944.
PLOT 21.

Rootstock	Mean total crop per tree (kg.) for 16 years	Rootstock	Mean trunk diam. (cm.) at 16 years
G 8	245.1	Mixed Seedlings	18.5
Mixed Seedlings	195.2	Hampshire Crab Seedlings	18.5
Hampshire Crab Seedlings	184.6	G 8	17.8

17. *Plot 22; Long Ashton (Standards).*

This trial consisted of two parts, the results of which are considered separately.

In the first part two-year-old standard trees on seven rootstocks were planted in December 1928. These had been worked low in the nursery and

the trunks therefore consisted of the scion variety. Two units, each containing four trees, on each stock were used.

In the second part rootstocks which had been allowed to run up to standard height in the nursery were planted, also in December 1928, and were head-worked with Bramley's Seedling in April 1931. The trees in the two series were therefore identical as regards age of rootstock and time of planting, but in the second series the trunks consisted of the stock variety and only the heads of Bramley's Seedling. The second part of the trial included two units, each of four trees, on the same clonal stocks as those used in the first part.

The site is that described under Trial 8, the plot containing alternate rows of Bramley's Seedling and Worcester Pearmain. Conditions and treatment were uniform throughout the plot.

TABLE XIII.
BRAMLEY'S SEEDLING, STANDARDS, 1928-1944.
PLOT 22.

Rootstock	Mean total crop per tree (kg.) for 16 years	Rootstock	Mean trunk diam. (cm.) at 16 years
G 8	363.5	G 8	20.2
E 7	216.0	E 7	17.5
F 11	199.3	G 7	16.4
G 7	177.9	F 2	16.2
F 10	158.2	G 6	16.1
G 6	123.6	F 11	14.9
F 2	62.6	F 10	14.7

TABLE XIV.
BRAMLEY'S SEEDLING, STANDARDS, (HEAD-WORKED) 1928-1944.
PLOT 22.

Rootstock	Mean total crop per tree (kg.) for 16 years	Rootstock	Mean trunk diam. (cm.) at 16 years
G 8	223.3	F 10	16.2
F 10	219.5	G 7	15.4
F 11	175.3	G 8	14.5
G 7	155.0	F 11	14.2
E 7	151.5	E 7	13.6
G 6	113.0	G 6	12.9
F 2	71.3	F 2	12.3

18. Plot D; Gloucestershire (Standards).

Five-year-old standard trees on eight rootstocks were planted in December 1931. There were seven trees, in units of four and three, on each of seven clone stocks, and seven trees on seedlings of Wootton Crab were also included.

In addition, a series of head-worked trees on some of the same clone stocks was planted. These were the same age but the stocks had been run up and head-worked in the nursery. Six clone stocks were included and there were again seven trees in two units on each stock.

The site is almost level, open to the north and east and adjoined by older orchards to the south and west. The soil is a typical heavy loam of the Bromyard Series derived from the Old Red Sandstone. In one corner of the plot there is a local appearance of the Shallow Bromyard soil, but only one or two trees were growing on that portion of the plot.

The land was old pasture and after planting was maintained as a grass orchard. In the early years the trees did not receive sufficient attention as regards spraying and pruning, but otherwise the management of the plot has been good. The young trees suffered to some extent from drought in 1934 and 1935, but since then they have grown well and made good trees.

By 1937 only a very small quantity of fruit had been borne, in 1938 all blossom was killed by frost, and in 1939 there was little blossom and a very poor crop. After this it was impracticable to obtain any records until 1944 and the amount of crop during this period is unknown, but the trees had evidently been growing well, as could be seen when they were inspected and measured in 1944.

In 1944 nearly all trees were bearing a fairly good crop and the weight on each individual tree was estimated. A mean figure for each rootstock obtained in this way suggested that the cropping performance of most of the stocks was very similar, G 8 possibly showing a slight superiority, but G 6 being definitely inferior. The size of the trees, as indicated by trunk diameter, for both low-worked and head-worked trees, is shown in the following table.

TABLE XV.
BRAMLEY'S SEEDLING, STANDARDS, 1931-1944.
PLOT D.

Low-worked trees		Head-worked trees	
Rootstock	Mean trunk diam. (cm.) at 13 years	Rootstock	Mean trunk diam. (cm.) at 13 years
Wootton Crab Seedlings	16.4	E 7	15.7
G 8	16.3	F 11	15.1
EM XIII	15.6	G 7	14.1
E 7	15.5	G 8	13.8
F 10	15.4	F 10	12.9
F 11	14.5	G 6	12.0
G 7	14.2		
G 6	13.3		

19. Plot B; Wiltshire (Standards).

Five-year-old standard trees were planted in January 1932. The rootstocks included six clonal stocks and one set of seedlings: there were two units, each of four trees, on each stock.

One unit of four head-worked trees on four of the stocks was also planted.

The site is level and open, except that it is bordered on the north by a hedge containing some large elm trees. The soil consists of Greensand over Gault clay and varies between a medium loam and a rather stiff clay.

The plot has been maintained in grass for most of the period of the trial, with poultry running in it, but during the war part of the area was planted with potatoes. The trees have suffered from lack of spraying when young, to some extent from drought in one or two years, from some very severe gales and from total destruction of the blossom by frost in 1935 and 1938. Crops were therefore very poor up to 1939 and during the war crop records were unobtainable; it is therefore impossible to present any useful data on the crops produced.

Of recent years the trees have made better growth and many of them were good when measured at the end of 1944.

TABLE XVI.
BRAMLEY'S SEEDLING, STANDARDS, 1932-1944.
PLOT B.

Low-worked trees		Head-worked trees	
Rootstock	Mean trunk diam. (cm.) at 13 years	Rootstock	Mean trunk diam. (cm.) at 13 years
G 8	18.3	F 11	16.0
Wootton Crab Seedlings	16.8	E 7	15.0
G 7	16.6	G 7	14.1
E 7	16.0	G 6	9.8
EM XIII	15.9		
F 11	15.3		
G 6	14.0		

20. Plot PL B; Somerset (Standards).

Five-year-old standards on six rootstocks were planted in December 1932. There were two units, each of four trees, for each stock with the exception of F 10, for which only one unit was available.

The site is level and is situated to the south of an old orchard. The soil, of the Taunton Series, is a heavy loam derived from Keuper Marl mixed with drift from the Greensand and contains flints: a clay loam is found at a depth of 15 inches.

The plot was clean cultivated when planted but was grassed down in 1934 and has since been maintained as a grass orchard and grazed. Management has been fairly good, but spraying has been rather neglected, with the result that attacks of caterpillar, aphid and scab have been rather bad at times. In spite of this the trees were, on the whole, very satisfactory in 1944.

Very few fruits had been borne up to 1937, in 1938 the bloom was poor and there was no crop owing to frost. In 1939 the whole plot bore a crop of 127 kg., but no details about the crop of individual trees were obtained. In 1940 the trees suffered to some extent from drought and there was a poor crop, the fruits being counted on the trees, while in 1941 blossom was poor

and considerably damaged by frost and there was no crop. In 1942 there was a total crop of 762 kg., but no details were obtained, and no information is available about the crop of 1943. In 1944 the crop on individual trees was estimated by inspection. There is thus very little reliable information about the cropping of the trees and the figures in the table below really represent almost entirely the estimated crop in 1944.

Trunk measurements at the end of 1944 are also set out in the table.

TABLE XVII.
BRAMLEY'S SEEDLING, STANDARDS, 1932-1944.
PLOT PLB.

Rootstock	Mean total crop per tree (kg.) for 1937, '38, '40, '41 and '44	Rootstock	Mean trunk diam. (cm.) at 12 years
G 8	34.5	EM XII	15.2
D 1	33.6	D 1	15.1
G 7	33.1	G 8	14.5
EM XII	28.6	G 7	14.3
F 10	27.2	F 10	14.1
F 11	14.6	F 11	10.8

21. *Plot R; Somerset (Standards).*

Five-year-old trees on three clonal stocks and on Wootton Crab seedlings were planted in December 1932. The number of trees on each variety of stock ranged from 9 to 19 and they were arranged in units of five or four trees. There were 15 seedling stocks which had been worked low and nine which had been head-worked in the nursery.

The site was a pasture with a very gentle slope to the south-west, bounded by an old orchard on the south-east. The soil, of the Worcester Series, is a heavy loam derived from Keuper Marl: clay occurs at a depth of 15 inches.

The plot was maintained as a grass orchard and grazed. Management was fairly good, though the trees would have benefitted from more spraying to control aphids in the early years. By 1944, however, most of the trees had made very good growth and were healthy and fairly clean, though there was some aphid and scab present.

Records of the crops are very scanty. Up to 1938 there had been very little blossom and negligible crops, and though there was more bloom in 1939 there was a poor crop, of which no records were obtained. In 1940 and 1941 there were again only poor or fair amounts of blossom, very poor crops and no records. In 1942 there was said to be a heavy crop on all trees but no records were made, while in 1943 there was practically no blossom or crop. In 1944 there was a good crop, that from individual trees being weighed, and the figures for crop weight in the table below represent the crop for 1944 only. Trunk diameters for 1944 are shown in the table.

22. *Plot M; Monmouthshire (Standards).*

Five-year-old standard trees on nine rootstocks were planted in December 1932. There were two units, each of four trees, on each stock, with the exception of A 3 for which there was one unit only.

TABLE XVIII.
BRAMLEY'S SEEDLING, STANDARDS, 1932-1944.
PLOT R.

Rootstock	Mean crop per tree (kg.) for the 12th year (1944).	Rootstock	Mean trunk diam. (cm.) at 12 years
EM XII	46.7	EM XII	17.0
G 7	37.2	Wootton Crab Seedlings	15.2
Wootton Crab Seedlings	33.1	G 7	14.7
„ (head-worked)	23.6	Wootton Crab Seedlings (head-worked)	12.4
G 6	20.0	G 6	12.0

The site has a moderate slope to the south-east, being open except at the north-west, where it is sheltered by a wood. The soil is colluvial at the top of the slope, but consists of medium to heavy loam of the Bromyard Series in other parts, with clay loam at 15 to 18 inches. Poor drainage of some parts of the plot was suspected when the trees were planted and afterwards it was found that this was worse than had been anticipated.

The plot was clean cultivated when planted, but was allowed to tumble down to grass and weeds the following year. Weeds were very bad at first, but later the ground was fairly well grazed and a fair sward was formed. On the badly drained parts of the plot trees suffered from waterlogging and at other times from drought. The trees received very little attention as regards pruning and spraying.

Under these conditions, up to 1939, the trees made very poor growth and were attacked by caterpillar, aphid, mildew and canker. In 1944 some trees on the more vigorous stocks, and in parts of the plot where soil conditions were better, had made quite good growth but many were extremely poor.

No records of the small crops borne before 1944 were obtained, but in that year the crop of each tree was estimated. The heaviest crops, about 17.7 kg. were carried by trees on F 11 and E 7, those on G 7 and EM XII being slightly lighter. Trees on G 8 bore a medium crop, but the yields of F 10, G 6, A 3 and B 2 were poor.

The largest trees were those on EM XII, followed by those on E 7, G 7, F 11, G 8, G 6, B 2 and A 3, in that order.

23. Plot KN; Worcestershire (Standards).

Five-year-old standard trees on eight clonal and 17 seedling rootstocks ("New Forest Crab") were planted in November 1933. There were two units of four or three trees on each stock, except in two cases where only one unit was available.

The site is level, very exposed and open on each side except to the west, where it is sheltered by an established orchard. The soil is a deep typical heavy Pershore loam derived from the Lower Lias.

The trees were planted in grass which was maintained until 1941, when it

was ploughed up, and various crops were grown after that date. There were serious drought conditions in 1934 and 1935 which checked all the trees very badly and killed some of them. None of the trees really started growing well until the grass was ploughed up, and in the earlier years they also suffered severely from inadequate staking, damage by hares and lack of spraying, manuring and pruning.

In 1944 only 43 trees were surviving out of the 64 which were planted, deaths having occurred on each clonal stock and on the seedlings. Most of the trees were poor or moderate and there were only a few satisfactory trees. There had been no appreciable crops. The only data worth recording appear to be the larger size of the trees on E 7, E 8 and the seedling stocks and the small size of those on F 12 and G 6. Trees on A 10 and F 10 were of intermediate size.

24. *Plot WN ; Herefordshire (Standards).*

Five-year-old standard trees on various stocks were planted at the beginning of 1935 in cultivated ground. The trees were badly neglected, a number of deaths occurred, and by 1943 nearly all the surviving trees were in a very poor condition.

Under these conditions the only fact worth recording is that the trees on EM XII and D 1 had made the most satisfactory growth. Other rootstocks in the trial were A 3, A 8, E 7, F 2, F 10, G 6, and G 8.

Newton Wonder.

25. *Plot 21 ; Long Ashton (Standards).*

Four-year-old standard trees on eight rootstocks were planted in December 1928. On each stock there were two units, each including five or four trees.

The site is that described under Trial 7 (Worcester Pearmain standards) and conditions and treatment were similar.

TABLE XIX.
NEWTON WONDER, STANDARDS, 1928-1944.
PLOT 21.

Rootstock	Mean total crop per tree (kg.) for 16 years	Rootstock	Mean trunk diam. (cm.) at 16 years
G 7	237.1	EM XII	21.0
D 1	227.6	G 8	17.8
G 8	221.2	D 1	17.2
E 7	184.6	G 7	16.4
F 2	147.4	E 7	14.1
EM XII	145.9	G 6	13.5
F 11	128.7	F 12	13.1
G 6	97.4	F 11	11.5

26. *Plot S ; Gloucestershire (Standards).*

Standard trees on nine rootstocks were planted in December 1930. The trees were five years old except those on EM XII, which were a year older.

This was a very small trial and there was only one unit, usually including five trees, on each stock.

The plot actually consisted of two separate portions, about a mile apart, but conditions on the two plots were so similar in every respect that the two plots have been regarded as one trial.

The sites were level and open and the soil was a heavy loam of the Badsey Series overlying calcareous gravel. Drainage was poor in some parts of the plots.

The trees were planted in grass and the plot was maintained as a grass orchard, being well grazed. The trees, however, received little attention and their growth and cropping was affected in the early years. The plot was badly drained in parts and trees planted in those areas were affected accordingly. In spite of these handicaps many of the trees afterwards grew well and carried a few good crops. No records of the crops are available except that trees on E 7 were probably the earliest to come into bearing and those on EM XII were bearing the heaviest crops in 1944.

Measurements in 1944 gave the following figures (cm.) for the diameter of the trunks :—

EM XII	E 7	G 7	D 1	G 8	F 10	F 12	G 6
18.7	17.1	15.6	15.4	15.1	13.6	12.0	7.3

All the trees on F 11 had died, but it was known that these were in a badly-drained patch of ground where they suffered alternately from waterlogging and drought.

27. Plot EL; Somerset (Standards).

Four-year-old standard trees on nine rootstocks were planted in February 1935. In most cases there were two units, each including four trees, on each stock, but two stocks were represented by one unit only.

The site is open and slopes gently towards the south. The soil is a brown fine sandy medium loam consisting of downwash mainly from Middle Lias material. Below 18 inches the soil is grey-brown with orange and blue-grey mottling and drainage is imperfect.

The plot was under grass when planted and was maintained in that state, but in at least one year a crop of hay was taken from it. The trees received very little attention and were adversely affected by neglect of staking, protection from livestock, spraying and manuring.

By 1941 nearly half the trees were in a poor condition, and, as it was desired to clear the field under a war-time ploughing-up scheme, the trial was abandoned.

Crops were negligible and no records are available.

The outstanding figures for trunk diameter in 1941 (6 years after planting) are as follows :—

Largest	EM XII	E 7	G 8	Smallest	G 6
	5.9	5.7	5.3 cm.		3.7 cm.

Blenheim Orange.

28. Plot 21; Long Ashton (Standards).

Four-year-old standard trees on nine rootstocks were planted in December 1928. There were two units, each consisting of four or five trees, on each stock.

The site is that described under Trial 7 (Worcester Pearmain standards) and conditions and treatment were similar.

TABLE XX.
 BLENHEIM ORANGE, STANDARDS, 1928-1944.
 PLOT 21.

Rootstock	Mean total crop per tree (kg.) for 16 years	Rootstock	Mean trunk diam. (cm.) at 16 years
G 7	81.1	EM XII	21.6
G 8	71.7	G 8	19.3
E 7	65.6	G 6	18.8
EM XII	59.8	F 10	16.3
G 6	55.0	D 1	16.2
F 10	47.0	E 7	14.5
F 11	47.0	G 7	14.3
D 1	40.6	F 12	13.7
F 12	34.9	F 11	11.6

Kingston Black.

29. Plot PLK; Somerset (Standards).

Two-year-old standard trees were planted in November 1928. This was a very small trial and included only one unit of six trees on each of three rootstocks, the scion variety being a cider apple.

The site is level, open to north-east and surrounded on other sides by other young standards. It is a few hundred yards from the site of Trial 20 and the soil conditions are similar.

The trees were planted in grass and the plot has since been maintained as part of a grass orchard. The trees have received little attention and have been affected by lack of pruning and spraying, and possibly by a deficiency of nitrogen, but they had made fair growth by 1944.

Crop weights were obtained in some years, but in several years the weight of crop was merely estimated: no records of the crops in 1939, 1942 and 1943 are available.

TABLE XXI.
 KINGSTON BLACK, STANDARDS, 1928-1944.
 PLOT PLK.

Rootstock	Mean total crop per tree (kg.) for 16 years (3 years omitted)	Rootstock	Mean trunk diam. (cm.) at 16 years
E 7	59.0	G 8	12.1
G 7	37.7	E 7	12.0
G 8	26.3	G 7	10.8

DISCUSSION.

Of the 29 trials described, only about 16 can be considered to be really satisfactory, and even in these the data collected are sometimes incomplete.

It is possible, however, to obtain from these trials a fairly complete and reliable picture of the performance of the stocks used under different conditions and worked with several scion varieties.

About ten of the trials were definitely less satisfactory. In some cases they appear merely to have demonstrated the impossibility of growing trees successfully on certain sites, whatever rootstock is used. In other instances they have shown the difficulty of establishing a good plantation or orchard unless the young trees receive proper care, and in the case of some of the grass orchards of standards the farmers have not had the knowledge or the facilities for providing the treatment needed by a young orchard. War-time conditions contributed to the failure of some of the trials. Even from the poor trials, however, it is sometimes possible to gain some information which supports the conclusions drawn from the better plots.

In the following discussion the data obtained are examined, each scion variety being considered in a separate section.

Worcester Pearmain.

Considering first the trees which have been grown in bush form, the data show that in the two most satisfactory trials, 1 and 4, the stocks associated with the heaviest crops are E 7, E 8, F 11, G 7, G 8, EM II and EM XII, though the order is not the same in both trials. The stock E 8 was included only in Trial 1, while F 11 and G 7 were included in Trial 4 only, where trees on F 11 bore slightly heavier crops than any others. The crops borne during the shorter life of the trees in the unsatisfactory Trials 2, 3, 5 and 6 show that the same seven stocks were always associated with the heaviest crops, though EM XII does not appear so high in the list as it does not encourage bearing as quickly as the others. Trees on A 10, D 1 and F 12 have been consistently among the poorest croppers in all these trials.

As regards tree size, stock EM XII has produced the largest trees in every trial except one, and in that case it was second on the list. Stocks E 7, F 11, G 7, G 8 and EM II have always been near the head of the list, but not always in the same order. Trees on E 8 show a tendency to be slightly smaller, while those on A 10, D 1 and F 12 have always been among the smallest.

In the trials with standard trees very similar results have been obtained. Stock EM XII was included in Trial 7 only, and there it was associated with the heaviest crops on 16-year-old trees. Stocks E 7, F 11, G 7 and G 8 produced trees with good crops in Trials 7, 8, 9 and 10, but crops from trees on D 1, F 12 and G 6 were generally poor.

The influence of the rootstock on the size of standard trees has been similar to that found in the case of bush trees. EM XII has produced much the largest trees, G 8 and E 7 probably the next largest, F 11 and G 7 slightly smaller, but trees on D 1, F 12 and G 6 have always been distinctly smaller.

The generally poor performance of Worcester Pearmain when worked low and run up to a tree of standard form was mentioned in a previous paper (3). The trials here considered confirm the view that such trees are really satisfactory only when grown on the most vigorous stock such as EM XII, though G 8, E 7, F 11 and G 7 have produced fairly good trees.

Rootstock G 6, when worked with Worcester Pearmain, has exerted a distinctly dwarfing influence, though trees have usually cropped well considering their size, but F 12 has produced trees which are both dwarfed and poor croppers. The stocks A 10 and D 1 appear to be largely incompatible with

Worcester Pearmain, and trees on these stocks have either been very stunted or, in a few instances, have grown well for a few years and then died suddenly.

James Grieve.

There is little to add to the account already published of the trials using this scion variety: Trial 12 was a total failure, but Trial 11 yielded some useful data before the trees were ruined by canker.

Of the rootstocks included in this trial EM II, E 7 and E 8 were associated with the heaviest crops, while F 12 produced poor croppers and A 10 and D 1 very poor croppers.

EM II produced the largest trees, those on E 7 and E 8 being distinctly smaller and those on F 12, A 10 and D 1 the smallest in the trial. Stocks A 10 and D 1 showed signs of incompatibility with the scion variety.

Laxton's Superb.

Though Trial 13 was carried on for a short time only it yielded some indications of the influence of the rootstocks used. Five years after planting the trees on E 7, E 8 and G 7 had borne the heaviest crops and EM XII the lightest (EM II was not represented in the trial). At eight years after planting, of the five stocks surviving, E 7 was associated with the best crops, followed by E 8 and F 11, while trees on EM XII were still carrying the smallest crop.

EM XII produced the largest trees throughout the trial, the next largest being those on E 7.

Lane's Prince Albert.

In Trial 14, after 16 years, the heaviest crop had been borne on trees on EM II, this being 50% better than the crop for G 7. The latter stock was closely followed by E 7, EM XII and G 8. Stocks E 8 and F 11 yielded a considerably smaller crop and the poorest crops were produced by D 1, A 10, and F 12.

For tree size the order is EM II, E 7, EM XII and G 7, this being one of the few cases in which EM XII did not produce the largest trees. G 8 produced rather smaller trees, E 8 and F 11 still smaller ones, and A 10 and D 1 the smallest trees, with signs of incompatibility.

The outstanding feature of this trial is perhaps the relatively poor performance of EM XII, G 8, E 8 and F 11 compared with that of the same stocks in other trials.

Cox's Orange Pippin.

Trial 15 was one of the latest to be planted but it has yielded useful data in its nine years of life.

As regards crop weights, EM II, G 7, E 7 and E 8 have been the most successful stocks, the crop from these being very nearly equal. G 8 and EM XII have yielded considerably lighter crops and the figures for F 11 and G 6 are smaller still.

The largest trees are on EM XII, and followed by those on E 7, EM II, E 8, G 7 and G 8. Trees on F 11 and G 6 are among the smallest in the trial.

The local variations in soil conditions have affected trees on all rootstocks and the trees in some of the units are very irregular in size and cropping. The performances of F 11 and G 8 are poor compared with those of the same stocks on other sites.

Bramley's Seedling.

Five of the nine trial plots including this variety are satisfactory, though cropping data are rather scanty in some cases, but three of the trials are definitely very poor and provided little information.

In Trials 16, 17, 18, 19 and 20, trees on G 8 were the heaviest croppers ; in Trial 21, which did not include G 8, stock EM XII produced the best crops. E 7 and G 7 have cropped well in most cases, but F 11, while good in Trial 17, was only moderate in other plots. Stock D 1 produced good crops in Trial 20. The use of G 6 resulted in a poor crop in every case.

The largest trees were on EM XII in the trials which included that stock, while in other trials the largest trees were those on G 8, G 7 or E 7. Stock F 11 was rather inconsistent in its effect on tree size in the various trials. It is interesting to note that D 1 produced large trees in Trial 20, and showed signs of a similar effect in the poor Trial 24. There appears to be no incompatibility between this stock and Bramley's Seedling. Whenever G 6 was included in a trial this stock produced the smallest trees.

Trees in Trial 17 on G 6 suggest that this stock has a very poor root-hold as they are sharply inclined as a result of exposure to gales, the effect being more pronounced on the trees which were headworked on run-up stocks. Headworked trees on E 7 also show this effect but low-worked trees on this stock appear to be much more firmly anchored.

In most cases trees which were worked low in the nursery have made better growth and been more productive than those which were headworked on run-up stocks. Stock G 6, in particular, appears to be unsuitable for running up and headworking.

Newton Wonder.

In the one good trial (No. 25) of this variety the best crops were borne by trees on G 7, D 1 and G 8, the performance of these stocks being very similar. The yields from other stocks were in the order E 7, EM XII, F 11 and G 6.

Tree size was in the order EM XII (much the largest), G 8, D 1, G 7, E 7, G 6 and F 11. Stock G 6 has again shown a poor performance and F 11 is unusually low on the list. It is noteworthy that D 1 has produced satisfactory trees with this scion variety.

Trials 26 and 27 have yielded no information about cropping except that E 7 probably promoted early bearing, and that among the older trees those on EM XII were possibly the heaviest croppers. As regards tree size, they confirm the evidence that the more vigorous stocks are EM XII, E 7, G 8, G 7 and D 1, while G 6 is the least vigorous.

Blenheim Orange.

Trial 28 provides the following data :—The heaviest crops were borne by trees on G 7 and G 8, followed by those on E 7, EM XII and G 6. Stock F 11 produced rather poorer crops and those from D 1 and F 12 were still lighter.

For size of tree EM XII heads the list, followed by G 8 and G 6. D 1 produced a medium-sized tree, those on E 7 and G 7 were rather small and those on F 11 the smallest.

With this scion variety the performance of G 6 has been relatively good, E 7 and G 7 have borne good crops on moderate-sized trees and F 11 moderate

crops on small trees. D 1 seems to be compatible with Blenheim Orange, as it has produced trees of a good size, but crops have been rather small.

Kingston Black.

Trial 29 was very small and rather unsatisfactory. The data available suggest that, of the three stocks, E 7, G 7 and G 8, included, E 7 has been associated with the heaviest crops and G 8 with the lightest. G 8 and E 7 produced trees of approximately equal size and larger than those on G 7.

GENERAL DISCUSSION AND CONCLUSIONS.

Data obtained from the trials at Long Ashton between 1939 and 1944 have confirmed the conclusions stated in the paper published in 1940 (3). The relative performance of the various rootstocks during the last five years of the trials has been almost exactly the same as in the previous period, the only notable exception being the increased crop produced by trees on EM XII, as they have become more mature. The standard trees have come into full bearing and have provided more information about the performance of the stocks when used for this form of tree. These additions to the available data do not suggest that there is any reason to modify the conclusions previously reached.

The trials on other sites in the neighbouring counties have very largely confirmed the results obtained at Long Ashton. Though trees have failed in some of the trials owing to adverse soil conditions, the failures have occurred with every rootstock. The trials were situated on very varied types of soil, but the relative performance of the rootstocks appears to have been very similar under all conditions. Where the management of young trees has been at fault, however, the more vigorous stocks have always given better results than the weaker ones.

The following conclusions have been drawn from a consideration of the trials as a whole :—

Good crops have consistently been associated with rootstocks E 7, E 8, F 11, G 7, EM II, G 8 and EM XII, but while trees of the first five stocks begin to crop fairly quickly, the use of EM XII always delays the start of full bearing and to a lesser extent this is also the case with G 8. Fairly good crops have been produced by trees on G 6 and bearing begins early on this stock. Crops have usually been poor on A 10, D 1 and F 12. Other stocks, such as A 3, A 8, A 9, F 2, and F 10, were used in some trials and their performance is recorded in the tables, but as this was usually mediocre or poor no further reference is made to them.

Rootstock EM XII is outstanding for its vigour and in almost every trial where it was used it produced much the largest trees. Stocks which have produced fairly large trees include G 8, E 7, G 7 and EM II and in some cases D 1. Good standards have been grown on all these, except EM II, which was not tried as a stock for standards. F 11 and G 6 produce a semi-dwarfing effect.

If the crop weight relative to tree size is considered the best results have been obtained from EM II, E 7, E 8, F 11 and G 7.

Stocks A 10 and D 1 have been found to be largely incompatible with Worcester Pearmain, James Grieve, Lane's Prince Albert and Laxton's Superb, but D 1 is compatible with Bramley's Seedling, Newton Wonder and Blenheim Orange.

The characteristics of the rootstocks in the stool-bed were described in a previous paper (3).

Taking all the data into consideration, it appears that F 11 and E 8 may be of value as semi-dwarfing rootstocks. E 7 and G 7 as more vigorous stocks comparable to EM II, and G 8 as a still more vigorous stock. Though the performance of E 7 has been excellent the spiny character of the plants obtained from the stool-bed reduces its attractiveness, and the performance of G 8 has been rather inconsistent.

SUMMARY.

1. A series of 15 clones of apple rootstocks, originally obtained from "free" and "Crab" seedlings and propagated by layering, were worked with nine scion varieties and the rootstock influences were studied in a series of trial plots. Trees on EM II and XII rootstocks were included for comparison.

2. The trial plots were situated at Long Ashton and on other sites in the West of England on a variety of soils. In some of the trials the trees were grown in bush form, in others as full standards. Trials were planted at different dates and the oldest trees from which records were obtained were 18 years old from the time of planting.

3. Rootstocks associated with the heaviest crops include E 7, E 8, F 11, G 7, EM II, G 8 and EM XII. With the first five stocks cropping commenced early and was heavy relative to the size of the tree. Full bearing was slightly delayed in the case of G 8 and distinctly so with EM XII.

4. Rootstock EM XII was associated with the largest trees, while G 8 produced rather smaller ones and those on E 7 and G 7 were similar in size to those on EM II. Stocks E 8 and F 11 had a semi-dwarfing effect. A 10 and D 1 were found to be incompatible with some scion varieties.

5. Rootstocks E 8, F 11, E 7 and G 7 may be of value, the two former as semi-dwarfing stocks, the two latter as more vigorous stocks comparable with EM II. G 8 may have a use as a still more vigorous stock. G 8 and possibly E 7 and G 7 are suitable for use as rootstocks for standard trees. None of the other rootstocks appear to be worthy of any further trial.

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Thanks are also due to Professor T. Wallace and Dr. D. A. Osmond for supplying information about the soils on the various sites.

REFERENCES.

- (1) HOBLYN, T. N. Trials of clonal apple rootstocks selected from "free" and "Crab" seedlings. II. Performance at East Malling when worked with Lane's Prince Albert. *Journ. Pom. and Hort. Sci.*, 1940, 18, 239.
- (2) SPINKS, G. T. Apple Rootstock Investigations. *Ann. Rpt. Long Ashton Res. Stn.*, 1930, p. 19.
- (3) SPINKS, G. T. Trials of clonal apple rootstocks selected from "free" and "Crab" seedlings. I. Performance at Long Ashton when worked with five scion varieties. *Journ. Pom. and Hort. Sci.*, 1940, 18, 226.

EXPERIMENTS IN MINERAL NUTRITION III.

THE VISUAL SYMPTOMS OF MINERAL DEFICIENCIES OF CROP PLANTS GROWN IN SAND CULTURE.

PROGRESS REPORT, SEASON 1945.

By E. J. HEWITT.

This report describes the work done in continuation of the survey of visual symptoms of mineral deficiencies of crop plants (1), (2), (3). Twenty-nine crops were grown in controlled large scale sand cultures. Particular attention was given to the production of calcium, iron and boron deficiencies. The improvements and modifications in both rainwater and distilled water techniques will be described in a separate report, together with details of analyses of sand, water and nutrients.

The differentiation between straightforward calcium deficiency and the interaction of low calcium with excess manganese (circumstances associated with soil acidity in the field) is described for cauliflower and runner bean in a separate report (4).

A. RAIN WATER SERIES.

Experimental.

Materials and Methods.

The general technique was similar to that described previously (2), (3). The trace element constituents of the nutrient solutions were incorporated with the other nutrients with each application instead of being supplied in a weekly supplement.

The new techniques to overcome previous difficulty in producing calcium, iron and boron deficiency symptoms included the use of double waxed, bitumen painted and plastic pots, rainwater purified by the Permutit Demineralisation process and more highly refined nutrients. A transplanting technique has been used in which the culture including all the sand can be transplanted to another pot treated to prevent the supply of nutrients from the pot. Adult plants transplanted in this manner show no apparent adverse effects specifically due to transplanting (as are often observed when the roots are separated from the sand), but severe effects due to sudden deficiency at an advanced stage of growth can be induced in a short time. The symptoms induced in this manner are indicated by the letters T/P and the age from sowing or initial transplanting in days or weeks in brackets, *e.g.* (T/P 6 weeks).

In the boron deficiency cultures a parallel series with double the normal nitrogen level was included to observe the effects of nitrogen level on the incidence of boron deficiency symptoms. In general it was found that the high nitrogen series were more severely affected by boron deficiency, *e.g.* curd breakdown of cauliflower, pith necrosis of kohlrabi, "raan" of swedes and "stemcrack" of celery were all greatly accentuated by additional nitrogen due possibly to the tendency for more rapid growth.

The crops grown and treatments given are shown in Table I.

TABLE I.
CROPS GROWN AND TREATMENT GIVEN.

Crop and Variety	Nutrient Elements Omitted
Wheat Red Marvel	Ca, Mg
Barley Plumage Archer	Ca
Oats White Star	K, Ca, Mg, Fe
Cabbage Winningstadt	Ca, Fe
Cauliflower Majestic	Ca, B, B with 2 × N level
Rape Black English	Ca, B
Marrowstem Kale Green	Ca, Fe, B
Hungry Gap Kale	B
Kohl Rabi Early White	B, B with 2 × N level
Turnip (White) Milan	B
Turnip (Yellow) Golden Ball	B
Swede Purple Top	Ca, B, B with 2 × N level
Mustard White	K
Radish Sparkler	N, P, K, Ca, Mg
Lettuce All Year Round	N, P, K, Ca, Mg
Carrot Early Market	Ca, B, B with 2 × N level
Parsnip Student	Ca, B, B with 2 × N level
Celery Market White	N, P, K, Ca, Mg, B, B with 2 × N level
Mangold Golden King	Ca, B
Sugar Beet	Ca, B
Globe Beet Detroit Globe	B
Broad Bean Monster Green Windsor	Ca, B
Runner Bean Scarlet Emperor	Ca
Pea Onward	N, P, K, Ca, Mg, B
Red Clover Dorset Marigras	N, P, K, Ca, Mg, Fe, B
Alsike Clover	Ca
Lucerne	Ca, B
Tomato Market King	Ca
Hops Fuggle	Ca

Results (Description of typical symptoms).

Wheat.

Omissions.

Calcium (5 weeks). Growth thin; leaves small, narrow, limp, colour pale; young leaves yellowing tips, wilting and collapsing 1–1½" behind tips (compare clovers); followed by recovery.

Magnesium (10 weeks). Old leaves bright yellow intervenal blotches, withering from tips.

Barley.

Calcium (6 weeks). Growth thin; tillering reduced; young leaves small, limp, paling from tips; recovering later.

Oats.

Potassium (9 weeks). Growth markedly stunted; tillering increased; colour pale, continuous intervenal yellow chlorosis of younger leaves, similar to iron-deficiency chlorosis.* Older leaves small dull orange-coloured watersoaked areas between veins spreading as diffuse red-brown areas mainly in centre of leaf or along margins, whole leaf becoming bronzed from tips and margins, finally severe red-brown scorching and withering of whole leaf; ear formation delayed, much reduced, glumes bronzed intervenally and frequently empty.

Calcium (5 weeks). Growth thin; tillering reduced; shoots lying horizontally on sand and tillering from nodes; leaves limp and chlorotic; recovering later.

Magnesium (8 weeks). Growth stunted; first symptoms; older leaves pale with diffuse banded mottling of light and dark green intervenal areas at first, dark areas becoming distinct in chains, like several adjacent strings of beads, more pronounced near margins and tips; followed by irregular, intermittent, ivory coloured intervenal necrotic areas; finally leaves pale yellow green with small irregular orange and green specks particularly near margins, withering from tips; ear formation greatly delayed, glumes dull grey-green.

Iron (9 weeks). Leaves erect; intervenal yellow chlorosis young leaves commencing from base of leaf, tips green; lower part of leaf becoming completely yellow, intervenal chlorosis extending to tips, finally whole leaf chlorotic; glumes yellow and frequently empty.

* Spraying with 0.1% FeSO₄ and spreader completely cured the symptoms of iron-chlorosis in K deficient plants and resulted in greatly increased growth and ear formation which was also earlier than in unsprayed plants.

Cabbage.

Calcium (T/P 6 weeks). Growth stunted; death of growing point; heart formation prevented; young leaves white rims with necrotic spotting within margins, necrosis and collapse of intervenal tissues near base of leaf; margins ceasing growth, cupping and tearing; youngest leaves chlorotic, tips and margins browning becoming infected with mycelium; old leaves dull white intervenal blotches near base.

Iron. Pale, no typical symptoms.

Cauliflower.

Calcium (T/P 6 weeks). Colour pale; young leaves tip hooking backward or forward (beaked), browning of tips and margins, fine intervenal necrotic spotting within margins; expanded leaves fine intervenal necrotic spotting generally, and slight intervenal chlorotic mottling followed by wilting and collapse of intervenal tissues with orange tint and brown scorching, margins remaining green.

Boron. Early symptoms—growth very stunted; death of growing point; young leaves hard, distorted, fasciated, colour dark green; old leaves thick and brittle, typical marginal tinting, corky roughening petiole and stem.

Late symptoms. (Observed in double nitrogen series after transplanting)—curd developing brown and purple tints at early stage with numerous small leaves between “segments” of curd, later complete necrosis and browning of curd, infection with mycelium and soft rot; stem pith brown watersoaked area, no chambering.

Rape.

Calcium (6 weeks). Younger expanded leaves, green margins, intervenal paling with yellow and orange tints followed by greying and upcurled marginal scorching and collapse of intervenal tissues; bracts, necrotic spotting and mottling; floral stems and pedicels, grey tints followed by wilting and collapse.

Boron (12 weeks). Death of axillary growing points; splitting of leaf base and stem; floral shoots aborted; brown discoloration of pith of floral stalks.

Marrowstem Kale.

Calcium (T/P 5 weeks). Growth stunted; death of growing point, including axillary shoots; young leaves marginal necrosis and browning with forward hooking and death of tips, finally only soft brown rudimentary petioles; expanded leaves margins green with necrotic spotting, wilting, collapse and brown intervenal scorching, margins finally curled up and scorched.

Iron (10 weeks). Growth stunted; young leaves fine chlorotic mottling between veins finally complete white intervenal chlorosis, only veins remaining pale green, older leaves pale and slightly mottled. Two plants showed “hollow stem” symptoms usually associated with boron deficiency.

Boron (T/P 6 weeks). Growth stunted; stem elongation rapidly checked after transplanting; young leaves distorted, margins necrotic, petioles roughened, curled back with grey tints; older leaves red or purple marginal tints, petioles very brittle; irregular diamond shaped inter-connected cavities in pith of transplanted specimen at the end of season and browning of pith in non-transplanted cultures.

Hungry Gap Kale.

Boron (15 weeks). Growth stunted; death of growing point; young leaves yellow, curled and distorted with browning of margins or at base, finally collapse and necrosis of lamina; oldest leaves red and orange marginal tints; petioles very brittle with corky splits or diamond shaped pitting in upper surface near base; stem pith central discoloration with constriction between wider sunken areas.

Kohl Rabi.

Boron (20 weeks—end of season). Youngest leaves in growing point brown; young leaves slight cupping and deformity of margins; older leaves intervenal paling, purple marginal tints; high nitrogen series slight marginal scorching (possibly low K) and longitudinal splitting of root; roots on cutting showed large irregular cavity usually near base of root, cavity interspersed with white strands of pith, margins and vascular tissue brown and watersoaked area just below crown in addition to cavity.

White Turnip.

Boron (10 weeks). Death and blackening of growing point followed by soft rot and multiple crowns; young leaves distorted and curled back, older leaves hard and crinkled between veins near mid-rib, colour dark green with yellow tints at margins, later scorched; root surface scaly, internal “water core” symptoms, dull grey-brown watersoaked necrosis in radiating concentric areas, with cavities formed by splitting.

Yellow Turnip.

Boron (10 weeks). Death of growing point; leaves slightly deformed, colour dark green with red or purple marginal tints; root medullary rays enlarged and corky; internal irregular brown watersoaked areas, large central cavity surrounded by rotting tissue.

Swede.

Calcium (7 weeks). Young leaves paling and cupping margins, hooking at tips; older leaves irregular cupping and scorching of margins.

Boron (10 weeks). Death of growing point followed by soft rot; older leaves purple tints round margins; roots irregular concentric brown water-soaked areas usually in centre with a secondary browning just below crown and extending upwards into neck but independently of soft rot; "raan" symptoms and internal splitting and cavities particularly severe in high N series.

White Mustard.

Potassium. Growth stunted, shortened internodes; old leaves convex, interveinal and marginal paling, yellow green, followed by inrolled pale brown scorch; stems thick and fleshy, only partially lignified; pedicels shortened.

Radish.

Calcium (10 weeks). Older leaves interveinal grey tints, wilting and collapsing within green margins; wilting and shrivelling of pedicels 1—3" behind flowers. Previously recorded symptoms of nitrogen, phosphorus, potassium and magnesium deficiencies confirmed.

Lettuce.

Calcium (8 weeks). Young leaves, tip burning with cupping and necrosis margins; followed by *Botrytis* infection. Previously recorded symptoms of nitrogen, phosphorus, potassium and magnesium deficiencies confirmed.

Carrot.

Calcium (12 weeks). Young leaves blackening and necrosis of leaflets commencing at tip; finally blackening and collapse of petioles; roots normal.

Boron (7 weeks). Death of growing point; young leaves chlorotic, becoming brown and withered, finally only rudiments of petioles; older leaves hard, leaflets deformed or with greatly reduced division or absent; colour dark green with yellow or red tints at margins, tip leaflets scorched; high nitrogen series, severe longitudinal splitting of roots and separation of cortex and vascular regions in addition to above symptoms, little or no discoloration below crown in middle of root.

Parsnip.

Calcium. No symptoms observed.

Boron (12 weeks). Young leaves browning and necrosis margins, older leaves transverse splitting upper surface and side of petioles (analogous to "stem crack" in celery) with backward bending; roots on cutting showed pithy cavity just below crown and grey water-soaked area in centre.

Celery.

Nitrogen (4 weeks). Growth very stunted, rosette habit; leaves small, colour pale yellow green, becoming yellow and withering, commencing with older leaves; petioles very short, yellow.

Phosphorus (6 weeks). Growth stunted, rosette habit; leaves small, dull, colour dark green becoming olive green, old leaves finally yellowing and withering; petioles short.

Potassium (7 weeks). Growth stunted; leaves convex, very shiny dark green, leaflets horizontal, slight marginal and interveinal paling with pale brown interveinal necrotic spotting within margins; oldest leaves yellowing and withering, with yellowing, browning and collapse of petiole; breakdown and death of growing point late in season with black soft rot in heart and blackening of young leaves from tips of leaflets in 2 plants.*

Calcium (7 weeks). Growth thin; colour pale; (all cultures) death of growing point, with black soft rot in centre; numerous thin axillary shoots; young leaves incurling, distortion and blackening tips and margins of leaflets, later involving whole leaf with blackening and collapse of petioles; older leaves normal, petioles elongated and smooth and straight (of boron deficiency).*

Magnesium (6 weeks). Pale; older leaves clearly defined marginal and interveinal yellow green chlorosis between major veins, becoming yellow; whole leaf finally complete white chlorosis including veins, with faint pink tinting at margins; petioles remaining green; no breakdown or soft rot of growing points.

Boron (7 weeks). Growth stunted; death of growing point, development of numerous axillary shoots; young leaves distorted, margins cupped, brown and scorched; old leaves, petioles twisted and bent irregularly with typical "stem crack." Symptoms accentuated and hastened in high nitrogen series.

* The necrosis, blackening and distortion of young leaves and subsequent death of growing point with black soft rot in the crowns observed in all calcium deficient and (late in the season) in two potassium deficient cultures has been described by Harmer and Benne (5) in America and attributed to damage by excess sodium. Sodium salts are used for replacement in both calcium and potassium and also magnesium deficiency cultures and the point requires further investigation as regards the inter-relation of calcium and potassium to sodium, particularly as no such symptoms appeared in the magnesium deficient cultures.

Mangold.

Calcium (14 weeks). Young leaves marginal incurling, marginal and intervenal bronzing followed by blackening with death of margins behind leaf tip producing typical forward hooking and folding back of lamina; roots normal.

Boron (4 weeks). Growth stunted; death of growing point; young leaves basal and marginal black necrosis, finally completely black; older leaves wilting, marginal paling, later marginal and intervenal dark brown scorching, finally shrivelling; veins bronzing and petioles bronze tint (early symptoms); petioles transverse corky splitting and roughening upper surface; roots internal dark cankerous cavities below crown.*

Sugar Beet.

Calcium (5 weeks). Colour pale; growing point very weak with "multiple crowns"; young leaves very narrow, blackening and death of margins just behind tips causing typical hooking forward or backward, lamina folded backwards, crinkled between veins; lamina progressively reduced and pointed, finally only blackened rudimentary petioles; black necrotic spotting sides of petioles; roots severe external irregular black splitting, internal black cavities below crown.*

Boron (3 weeks). Death of growing point, followed by death of plant (severe cases) or "multiple crowns" condition; young leaves narrow, basal and marginal blackening finally involving whole leaf; older leaves deformed with intervenal crinkling along midrib; roots normal.

Globe Beet.

Boron. Growth very slow; young leaves narrow, erect, colour dark red or nearly black; roots trace black canker about sand level in surface zones.

Broad Bean.

Calcium (12 weeks). Growth spindly; death of growing point; black necrosis of shoot at time of emergence through sand †; tip and marginal blackening and death of young leaves; blackening and early dehiscence of younger flowers without setting.

Boron (10 weeks). Growth stunted; death of growing point; leaflets pointing acutely upwards, colour pale, orange and pink marginal tints, followed by marginal browning and rapid defoliation; early dehiscence of flowers; roots stunted, brown, nodules absent.

Runner Bean.

Calcium (11 weeks). Death of growing point, some shoots with die back; leaves pale yellow (low N effect), marginal and intervenal brown necrotic spotting and tip browning, marginal paling and slight intervenal mottling; young pods yellowing, few older pods soft and yellow some weeks after setting, death of pods occurring from distal end of "truss"; roots brown and stunted.

Pea.

Calcium (6 weeks). Growth stunted; death of growing point; young shoots damaged on emergence, colour grey; cupping and yellowing young leaves, leaflets folded, pale; intervenal necrotic spotting and black markings in veins and petioles; older leaves faint intervenal mottling.

Boron. Growth stunted; shoots pale, young leaves tip browning and marginal distortion intervenal crinkling; pods small and distorted.

Typical symptoms of deficiencies of nitrogen, phosphorus, potassium and magnesium confirmed from 1944.

Red Clover (1943 series).

Calcium. Marginal scorching and occasional magnesium deficiency type symptoms generally; wilting and collapse young shoots, and pedicels *mature* flower heads.

Red Clover (1945 series).

Calcium. Slight intervenal chlorosis younger leaves responding slightly to ferric citrate applications.

Iron (6 weeks). Generally pale, young leaflets intervenal yellow green becoming complete yellow chlorosis with some intervenal brown necrosis.

Boron. Young seedlings stunted; colour dark green, leaves distorted and rudimentary; subsequently recovered with no further symptoms.

Typical symptoms of deficiencies of nitrogen, phosphorus, potassium and magnesium deficiencies were observed as in 1943 and 1944.

Alsike Clover.

Calcium (8 weeks). Growth spindly; yellow green intervenal chlorosis and occasional purple brown flecking near midrib, marginal scorching and irregular pale brown or white marginal

* Internal cavities were also observed in sugar-beets suffering from potassium deficiency in the presence of a high sodium level.

† Possibly damage caused by excess sodium.

spotting; wilting and collapse petioles of younger leaves, and pedicels of *young, opening* flower heads.

Lucerne.

Calcium (12 weeks). Yellowing shoots and young leaves; wilting and collapse pedicels, and dehiscence of flowers without setting seed.

Boron. Growth stunted; seedling stage, leaves hard leathery, distorted or rudimentary, colour dark green.

Tomato.

Calcium (8 weeks). Growth very stunted; death of growing point; young leaflets folded, colour pale, yellowing margins followed by brown scorching and shrivelling commencing from tips; middle leaves central orange intervenal tinting, margins and lower sides purpling, finally shrivelling from tip of spray; younger trusses, flowers shrivelling from tip of "truss," one or two fruit set at basal end only; complete withering of youngest trusses.

Hops.

Calcium (1944 cultures). Growth thin; death of growing point; die back of main and lateral shoots; younger leaves down-curling of margins, colour pale with marginal chlorosis, and necrotic spotting becoming narrow brown marginal scorch.

B. DISTILLED WATER SERIES.

The distilled water series was devoted solely to the study of boron deficiency and 14 crops were grown.

Experimental.

The crops were as follows (the varieties being the same as those grown in the rainwater series): Wheat, Barley, Oats, Cauliflower, Swede, Radish, Mustard, Carrot, Parsnip, Sugar Beet, Globe Beet, Red Clover, Lucerne, Flax (Liral Prince), Tomato, and Potato (Majestic).

Generally speaking the pots caused considerable contamination soon after initial deficiency effects had developed, but successful results were obtained in most crops by means of the transplanting technique described above, or resowing in double waxed or bitumen painted pots. The technique included the purification of nutrients by triple re-crystallisation. The full details of the technique will be described later in a separate report.

Description of Typical Symptoms.

Cauliflower.

(4 weeks). Growth very stunted; death of growing point; young leaves narrow becoming rudimentary, margins curled back, brown intervenal necrosis at base, finally completely withered; older leaves fasciated, curled back horizontally, hard leathery, mottled yellow green with orange and purple tints at margins and purpling generally on underside; corky roughening petioles and stem; roots brown and poorly developed; death of plant.

Swede.

Killed at seedling stage in 4 weeks.

Mature plants (10 weeks old). (T/P 3 weeks). Death of growing point; young leaves wilting, marginal and intervenal grey tint becoming brown and shrivelled, margins forward curling; older leaves brittle, thick, and hard, curled back, bright red marginal tints, intervenal yellow, orange and red marbling; petioles very brittle, longitudinal splitting corky ridges upper surface; roots typical severe "raan" symptoms; death of plant.

Radish.

(4 weeks). Growth stunted; death of growing point; young leaves rudimentary, laminae defective, petioles curled back and browning from tips; older leaves backward curling, intervenal crinkling; roots failing to swell, elongated and woody, cortical tissues brown and sloughed away, vascular tissues exposed and brown with irregular watersoaked areas internally.

Mustard.

(4 weeks). Growth stunted; death of growing point and plants; shoot tip bent to side, chlorotic, then brown; young leaves, pale becoming rudimentary, lacking lamina, petioles stunted and curled back; older leaves, purple and orange tinting margins and underside; roots brown.

Carrot.

(T/P 8 weeks). Growth stunted; death of growing point; young leaves stunted curled back, hard, colour pale yellow green with pink marginal tinting, browning and withering; older leaves distorted, leaflets often absent leaving petioles bare; petioles with brown corky splits along upper surface; tap roots corky splitting at surface near crown, medullary rays much enlarged, frequently deep longitudinal splits; lateral roots coarse and stunted.

Parsnip.

(12 weeks). Growth very stunted; numerous shoots from crown of root; young emerging leaves brown, distorted; expanded leaves hard, twisted, distorted, laminae defective, intervenal crinkling, colour pale with intervenal chlorosis and red marginal tints and intervenal marbling; petioles irregular twisting with transverse cracking sides and upper surface; tap root stunted, brown, medullary rays enlarged and protruding; lateral roots stunted, coarse, swollen and brown.

Sugar Beet.

(2-3 weeks). Growth stunted; death of growing point, followed by death of plant or "multiple crowns"; youngest leaves black, young leaves erect, twisted, colour pale green with black marginal and intervenal necrosis base of leaf.

Globe Beet.

Seedlings (4 weeks). Growth stunted; death of growing point followed by "multiple crowns"; leaves distorted, elongated strap shaped, thick, and hard, colour dark red-black.

Transplanted (6 weeks). Growth stunted; growing point weak, "multiple crowns"; young leaves strap-shaped, hard, colour dark red or black; older leaves intervenal crinkling; petioles transverse splitting over vascular bundles; root, corky scales near crown, surface cankers at sand level.

Red Clover.

Seedlings (3 weeks). Growth stunted; death of growing point; young leaves rudimentary, colour pale green, finally brown and dead; old leaves hard, colour dark green with red marginal tinting; petioles curled back; roots coarse, and brown; death of seedlings.

Established plants (T/P 5 weeks). Growth stunted; death of axillary growing points after cutting back; leaves thick, colour dark blue green with purple marginal tints; leaves from side shoots distorted and chlorotic; flower heads shrivelling before opening; roots coarse, stunted, brown, lacking nodules.

Lucerne (Inoculated).

Seedlings (2-3 weeks). Growth extremely stunted; death of growing point; first leaf only developed, remaining rudimentary and thick, colour dark green with red marginal tints; petioles curved back; roots coarse, scarcely branched, brown, nodules absent; death of seedlings.

Mature plants (T/P 4 weeks). Growth stunted; young leaves intervenal grey tinting centres and base of leaflets (commencing on floral shoots) becoming pale with tip and intervenal necrosis, finally bright yellow or orange with severe defoliation; older leaves hard, colour dark green with red marginal tinting; flowers falling without setting seed; roots coarse stunted brown, nodules few.

Flax.

(3 weeks). Growth very stunted; death of growing point; elongation of 1st internode prevented; chlorosis of youngest leaves, yellowing of cotyledons from base and centre; roots coarse, poorly branched, brown; death of seedlings.

Tomato.

(T/P 4 weeks). Growth very stunted; death of growing point including side shoots; (preceded by) chlorosis and browning of youngest leaves after bending sideways of shoot; young leaves hard, margins upcurled, colour pale from base of basal leaflets, centres yellowing, margins green with red tints and necrosis, purple veins particularly underside; leaflets very brittle; petioles curled back; older leaves dark green; younger fruit trusses withered or early dehiscence of shrivelled unopened flowers; older trusses withered at distal end, fruit set at basal end ripening with corky ring round base of fruit, many fruit small, distorted with corky pitting or ridges, ripening delayed 3-4 weeks; roots coarse, stunted brown, dead at tips.

Potato.

(9 weeks). Growth bushy and stunted, haulms thin; death of growing point; young leaves, leaflets folded or margins incurled, wilted, colour dark green, paling with yellow or orange tints basal margins and intervenally; necrosis at base of attachment young leaflets; petioles curled back; tubers small, with irregular brown corky scales, vascular ring brown, brown necrosis of tissue around growing points, central darkening; small tubers rotted.

SUMMARY.

1. The survey of typical visual symptoms of mineral deficiencies has been continued for 29 crops grown in sand culture.

2. Refinements in technique included the use of the Permutit demineralisation method for purification of rainwater used for iron deficiency cultures and highly purified nutrients for iron and boron deficiencies. New methods of pot treatment, including double waxing, bitumen paint and plastics, have been successful for producing calcium and boron deficiencies.

3. A method for transplanting adult plants complete with sand and with minimum root disturbance has been used to produce severe deficiency symptoms of calcium boron or other trace elements in a short space of time.

4. The following deficiencies are described:—Nitrogen, phosphorus, potassium, calcium and magnesium in celery; potassium in oats and mustard; calcium in wheat, barley, oats, cabbage, cauliflower, rape, marrowstem kale, radish, swede, lettuce, carrot, mangold, sugar beet, broad bean, runner bean, pea, red clover, alsike, lucerne, tomato and hop; magnesium in wheat and oats; iron in oats, marrowstem kale and red clover; boron in cauliflower, rape, marrowstem kale, hungry gap kale, kohlrabi, yellow and white turnip, swede, radish, mustard, carrot, parsnip, celery, mangold, sugar beet, globe beet, flax, broad bean, pea, red clover, lucerne, tomato and potato.

5. A high nitrogen level accentuated symptoms of boron deficiency.

6. The effect of increased sodium supply on celery in calcium and potassium deficiency cultures requires further investigation.

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REFERENCES.

- (1) WALLACE, T. (1943-44). "The Diagnosis of Mineral Deficiencies in Plants." A colour atlas and guide (with supplement). H.M.S.O., London.
- (2) HEWITT, E. J., (1943). *Annual Report, Long Ashton Research Station*, p. 31.
- (3) HEWITT, E. J. (1944). *Ibid*, p. 50.
- (4) HEWITT, E. J. (1945). *Ibid*, p. 51.
- (5) HARMER, P. M. and BENNE, E. J. (1945). *Soil Science*, **60**, 137.

THE RESOLUTION OF THE FACTORS IN SOIL ACIDITY.

PROGRESS REPORT I. SEASON 1945.

By E. J. HEWITT.

Failures from soil acidity in the field are remedied in practice by applications of lime which, in addition to neutralising acidity, supply calcium to the soil. Thus in attempting to explain the harmful effects of soil acidity, effects due to low pH and to low calcium supply require examination. Experiments at Long Ashton, using controlled sand cultures (1), (2), (3), have shown that the visual symptoms of calcium deficiency in many crops differ markedly

from those which occur under acid conditions in the field (4), and further, that many crop plants may be grown successfully using nutrient solutions with pH as low as 3.6. Other workers (5), (6), have also demonstrated the ability of many plants to grow successfully in both water and sand cultures at pH values below 4.

It would thus seem that factors other than calcium deficiency and low pH are responsible for many of the so-called acidity effects as they appear in the field and that problems of crop failures on acid soils are complex.

Since "failure" plants on acid soils often show very characteristic symptoms, experiments have been commenced to see how far visual symptoms may be used to determine the various contributory factors. Preliminary results obtained in these investigations have already been reported (7).

Among the possible factors involved the following require consideration :—

- I. Direct low pH (acidity) effects.
- II. Indirect effects of low pH which in soils may result in :—(a) greatly increased availability of such elements as manganese, iron, zinc, copper and aluminium to the point of toxicity. (b) Fixation of phosphate which may become deficient.
- III. Low calcium status which may result in calcium deficiency.
- IV. Generally low base status which may be a complex of calcium, magnesium, potassium and sodium deficiencies.
- V. Biotic factors, for example :—(a) failure of bacterial activity in the nitrogen fixing cycle resulting in nitrogen deficiency, (b) damage due to fungi such as the "finger and toe" organism in brassicae, and (c) the inhibition of mycorrhizal associations (8).
- VI. Molybdenum deficiency may be involved (9); this element appears to be less available under acid conditions, and there are several reports of the importance of lime for molybdenum uptake (10), (11), (12).

EXPERIMENTAL.

A preliminary experiment was set up using the sand culture technique to test the effects of some of the possibilities mentioned under II and III above. A range of indicator crops was also grown in an acid soil in pots under glass for purposes of comparison.

Materials and Methods.

Cauliflower (Majestic) and Runner Bean (Scarlet Emperor) were selected on account of the easily recognisable symptoms shown by these crops under acid conditions in the field and also because the symptoms are totally different in type in the two crops.

The special treatments given were as follows :—

- Series 1. No added calcium, but a low level of Ca obtained by the plants from the pot.
- Series 2. Medium calcium (Ca 67 ppm.)
- Series 3. High calcium (Ca 337 ppm.)

Each of these series had the following manganese and aluminium levels super-imposed.

- | | | | |
|----------|-------------|--------------|-------------|
| Basic Mn | (0.3 ppm.) | and Basic Al | (0.3 ppm.) |
| Med. Mn | (12.3 ppm.) | and Basic Al | (0.3 ppm.) |
| High Mn | (25.3 ppm.) | and Basic Al | (0.3 ppm.) |
| Basic Mn | (0.3 ppm.) | and Med. Al | (5.3 ppm.) |
| Basic Mn | (0.3 ppm.) | and High Al | (10.3 ppm.) |

The medium and high aluminium levels were raised from 2.7 and 5.3 ppm. respectively after 5 weeks from planting.

The calcium (above the medium level) in the high calcium series was supplied as $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. Phosphorus was supplied at 20 ppm. to all cultures, *i.e.* one-half the normal phosphorus level in the Long Ashton complete nutrient solution. The remaining nutrient ions were present in the usual concentrations for the type 2 solution (1), (2). The special treatments for manganese and aluminium were commenced a week after transplanting the cauliflowers and 10 days after emergence of the beans. The pH values of the various solutions in these treatments and the pH of the cultures observed after leaching with a minimum quantity of water were as follows:—

TABLE I
EFFECT OF ADDITIONAL MN AND AL ON pH OF NUTRIENT.

Series	Mn and Al levels		pH of Solutions	pH after leaching (bulk sample from 3 pots)	
				Runner bean	Cauliflower
1. Low Ca	Mn 0.3	Al 0.3 ppm.	5.90	8.06	8.13
	Mn 12.8	Al 0.3 "	5.93	8.10	8.47
	Mn 25.3	Al 0.3 "	5.85	8.16	8.60
	Mn 0.3	Al 5.3 "	4.12	8.31	8.56
	Mn 0.3	Al 10.3 "	3.58	8.30	8.61
2. Med. Ca (67 ppm.)	Mn 0.3	Al 0.3 "	5.70	8.18	8.68
	Mn 12.8	Al 0.3 "	5.78	8.21	8.36
	Mn 25.3	Al 0.3 "	5.50	8.30	8.40
	Mn 0.3	Al 5.3 "	3.90	8.40	8.40
	Mn 0.3	Al 10.3 "	3.60	8.37	8.29
3. High Ca (400 ppm.)	Mn 0.3	Al 0.3 "	5.70	8.24	8.34
	Mn 12.8	Al 0.3 "	5.68	8.45	8.51
	Mn 25.3	Al 0.3 "	5.48	8.13	8.56
	Mn 0.3	Al 5.3 "	3.93	8.00	8.44
	Mn 0.3	Al 10.3 "	3.67	7.91	8.46

In making up the solutions two points of interest were noticed. First—aluminium phosphate was immediately precipitated but the manganese did not apparently precipitate for at least some time. Second—the pH values of the solutions containing toxic concentrations of manganese are similar to the normal (5.5—6.0), but a considerable increase in acidity occurs on the addition of aluminium sulphate. (Note, however, that the pH of nutrient solutions used in 1943 was about 3.6, due to the use of ferric chloride, but growth was vigorous and normal.)

The methods of pre-treatment of sand, pest control, watering, etc., were as previously described (1), (2).

In addition to the observation of visual symptoms the petioles were sampled at intervals for tissue test analysis (13). Leaf material was also sampled for complete chemical analyses, the results of which will be reported later.

An acid soil of the Pershore heavy sand type from a market garden near Evesham was used for the soil comparisons. Severe symptoms of acidity had been recorded on cauliflowers, runner beans and other crops from this area. The soil was put into 10" waxed pots and planted or sown with lucerne, tomato, potato, sugar beet, cauliflower and marrow stem kale. After planting was

completed the soil was covered with a thin layer of washed quartz gravel to prevent caking of the surface.

Results.

Sand Cultures. Generally speaking, although no additional calcium was supplied in the low calcium series, the calcium obtained by root action from the waxed pots was sufficient to prevent the appearance of typical severe calcium deficiency symptoms in many of the cultures.

In the high calcium series mild symptoms of potassium deficiency developed for a time about the middle of June in both crops, but did not progress beyond the stage of occasional marginal paling and inrolled scorching of some of the oldest leaves in the runner bean and characteristic backward curving and slight tip and inrolled marginal scorching in the cauliflower. The runner beans also responded to increased calcium supply by producing larger leaves. Increased calcium increased the water requirements of the cauliflower but not of the beans (see Table II).

The calcium level greatly modified the appearance of the manganese toxicity symptoms in both crops. The increased calcium not only reduced the severity of the symptoms but also delayed their appearance by about two weeks for each increase.

Raised aluminium treatments produced symptoms suggestive of low phosphate status in the beans but not in the cauliflowers.

TABLE II.
EFFECT OF CALCIUM LEVEL ON SEVERITY OF MANGANESE TOXICITY.

Series (all receiving high manganese)	Crop	Toxicity Symptoms and Water Requirements		
		23/5/45= 5 weeks	7/6/45 = 7 weeks	Total consumption of water in gallons
Low Ca	Cauliflower			224
	Runner bean	Trace Moderate	Severe Severe	217
Medium Ca ..	Cauliflower			263
	Runner bean	No symptoms Slight	Slight to Moderate Moderate	221
High Ca ..	Cauliflower			319
	Runner bean	No symptoms Trace	Trace Slight	213

Tissue tests reflected these general observations for calcium and manganese (Tables IIIa and IIIb).

DESCRIPTION OF TYPICAL SYMPTOMS.

Runner Bean.

Low Calcium Series.

Basic Manganese and Aluminium. Growth lacking vigour; leaves reduced in size, generally pale, similar to low N effect; younger leaves fine intervenal mottling; older leaves slight marginal and intervenal whitish marbling, browning and necrotic spotting tips and margins, finally general yellowing as in low N; pods yellowing and wilting soon after setting.

Medium and High Manganese. Special symptoms were produced from these treatments which are ascribed to manganese toxicity. (See Figure 1.) (Medium manganese treatment symptoms included all stages in high manganese but were less marked). Leaves reduced in size, dark green; Ca deficiency symptoms masked; first symptoms in younger leaves as marginal, later smooth intervenal, yellow green chlorosis between major veins (fine veins obliterated); old leaves marginal and intervenal diffuse yellow or white marbling; purple or brown fine intervenal necrotic spotting of old and young leaves, becoming profuse in older leaves; considerable marginal necrotic spotting (compare low Ca); young leaves finally becoming distorted due to intervenal crinkling of margins near tip; petioles green with black speckling;



Fig. 1. Runner bean. High-manganese treatment. Comparison of manganese toxicity symptoms at high (left), medium (top right) and low (low right) calcium levels (June 18, 1945).



Fig. 2. Cauliflower. *a*, Calcium deficiency symptoms with low-(normal)-manganese. *b*, *c* and *d*, High-manganese treatment. Comparison of manganese toxicity symptoms at high (*b*), medium (*c*) and low (*d*) calcium levels (July 6, 1945).

Pods reduced in size and number. These symptoms were identical with symptoms of acidity in runner beans in the field.

Medium and High Aluminium. Growth lacking vigour; leaves small, dull dark green, becoming olive green; oldest leaves finally yellowing with severe premature defoliation; marginal and intervenal purplish necrotic areas along veins; (probably masked low Ca symptoms); petioles purple; pods reduced in size and number, frequently yellowing and withering.

Medium Calcium Series.

Basic Manganese and Aluminium. Growth normal, leaves medium size, medium green; trace marginal necrotic spotting as for low calcium.

Medium and High Manganese. Symptoms similar to the comparable low calcium series, but much less intense; intervenal paling young leaves and mottling of older leaves less distinct; necrotic spotting less profuse; trace brown necrotic spotting on margins and finally slight distortion of young leaves; petioles green, with black spotting. Symptoms delayed about 2 weeks in comparison with low calcium series.

Medium and High Aluminium. Growth lacking vigour; leaves smaller than basic level, dull dark green, becoming olive green, later yellowing with premature defoliation; trace marginal necrotic spotting; petioles purple.

High Calcium Series.

Basic Manganese and Aluminium. Growth vigorous; leaves large, medium green; no marginal necrosis; mild potassium deficiency in most cultures but more marked in basic series.

Medium and High Manganese. Slight marginal and intervenal mottling of young leaves and diffuse marbling of old leaves; trace necrotic spotting; no distortion or crinkling; pods normal. Symptoms delayed several weeks when compared with low calcium series.

Medium and High Aluminium. Vigour improved over lower Ca series but still less than basic type; leaves thin, small, dark green, yellowing in high aluminium treatment; petioles purple; pods reduced in number.

Cauliflower.

Low Calcium Series.

Basic Manganese and Aluminium. Young leaves slight marginal paling; middle leaves intervenal grey-brown tinting and wilting, margins remaining green; (typical mild low calcium symptoms) slight tendency for lamina to be continuous to base of petiole.

Medium and High Manganese. (See Figure 2.) One plant partly recovering from high manganese treatment developed severe calcium deficiency symptoms late in the experiment as follows:—death of growing point; hooking of tips of young leaves and loss of lamina on blackened petiole; necrosis of margins of middle leaves and necrosis of vascular tissue, and browning, wilting and collapse of intervenal tissue within margins; no curd formed. Symptoms ascribed to high and medium manganese treatments:—first symptoms; young leaves, slight paling of margins and severe incurved “cupping” and restricted marginal growth; margins becoming ragged and torn, fine necrotic spotting in marginal zone appearing later in older leaves, with faint intervenal mottling. (With the medium manganese treatment the cupping was less severe and the leaves less torn.)

Medium and High Aluminium. One plant receiving medium aluminium showed moderate calcium deficiency symptoms with intervenal collapse of tissue and vascular necrosis in middle leaves and tip hooking of young leaves; remaining cultures showed only mild calcium deficiency symptoms.

No characteristic symptoms observed with excess aluminium except slightly reduced vigour and tendency for lamina to continue to base of petioles.

Medium Calcium Series.

Basic Manganese and Aluminium. Plants normal except for slight tendency for lamina to continue to base of petiole.

Medium and High Manganese. Typical manganese toxicity symptoms but much less severe than in low Ca series; moderate cupping of younger leaves with slight tearing of margins; intervenal mottling and necrotic spotting close to margins and slight paling of rims; no signs of calcium deficiency.

Medium and High Aluminium. Normal, except for slight tendency for lamina to continue to base of petiole.

High Calcium Series.

Basic Manganese and Aluminium. Leaves larger than in low and medium calcium series; mild potassium deficiency symptoms including early flowering.

Medium and High Manganese. Manganese toxicity symptoms mild; slight cupping and marginal tearing; trace paling and necrotic spotting at margins; *considerable recovery later in season with medium manganese and moderate recovery with high manganese*; mild potassium deficiency.

Medium and High Aluminium. Growth less vigorous than basic series, leaves smaller; slight tendency for lamina to continue to base of petiole; mild potassium deficiency.

Tissue Tests.

The results of the tissue tests clearly showed the relation between manganese accumulation and the severity of the acidity symptoms in both plants. The effect of increasing calcium supply in restricting manganese accumulation was also evident. Increasing calcium supply reduced the amount of extractable aluminium in the early sampling, but very little aluminium could be extracted from petioles at the time of the second sampling. There was a reduction in the extractable phosphate at the end of the season in the petioles of both plants where the aluminium level was raised. No effect of excess manganese on extractable phosphate was noted.

Soil Cultures. The most striking result obtained from the soil experiment was the fact that the different crops not only showed different responses to the acidity conditions but also showed symptoms of a number of mineral deficiencies as well which varied according to the particular crop concerned, and included those of nitrogen, phosphorus, calcium, magnesium and potassium.

The tissue tests indicated accumulation of excess manganese in all the crops, but the calcium status was medium throughout.

DISCUSSION.

While these preliminary experiments have produced some clear indication of the nature of at least one set of interacting factors in the problems of soil acidity, it is too early for detailed discussion of the problems as a whole. Certain points, however, deserve special attention at this stage.

Calcium as an element clearly antagonises the intake of manganese under sand culture conditions, independently of the effect of liming in reducing the availability of manganese in the soil by raising the pH. The field symptoms of acidity in cauliflower and runner bean (although differing greatly in type) were reproduced closely by excess manganese at low calcium levels at a pH of 5.5 which normally gives excellent growth. Earlier experiments (1), (2), (3), have shown that field symptoms of acidity are not reproduced by calcium deficiency alone, even at a pH of 3.6 when the manganese supply is normal.

The slight accumulation of aluminium in the petioles early in the season was reduced in the cauliflower, and to a lesser extent in the runner bean, by increasing calcium supply. Later in the season aluminium could not be detected and the extractable phosphate in the petioles was reduced in the raised aluminium treatments. This result suggests that immobilisation of both as aluminium phosphate had occurred since the time of the first sampling, possibly in the root (14). Excess manganese had no effect on extractable phosphate.

A case of molybdenum deficiency in cauliflowers growing in very acid soil has been reported from New Zealand (9). The uptake of this element is increased by liming, and attention must be directed in future work to the possibility that molybdenum deficiency may be involved in some cases of failure due to soil acidity. The cause of the white rims and marginal marbling frequently observed in the leaves of young cauliflower and kale plants growing in acid soils also requires further elucidation.

A reciprocal manganese-iron relationship, in which an excess of one element may produce symptoms resembling a deficiency of the other, has been observed in solution culture experiments in a number of plants, including soya bean (15), and strawberry and cape gooseberry (16). The possibility that the chlorosis of the younger leaves of the runner bean was of this induced iron deficiency type was examined in the following manner. Ferric citrate

TABLE III.
CAULIFLOWER.
RESULTS OF TISSUE TESTS ON PETIOLES.
Date Sampled 15/6/45. (1st and 2nd Upright Leaves).

Test for		Low Calcium					Medium Calcium					High Calcium				
		Basic Mn & Al	Med Mn	High Mn	Med Al	High Al	Basic Mn & Al	Med Mn	High Mn	Med Al	High Al	Basic Mn & Al	Med Mn	High Mn	Med Al	High Al
K*	..	M	M	M—	M	M—	H—	H—	H—	H—	H—	L	L	L	L	L
PO ₄ '''	..	M—	M+	M	H	M	M+	H—	H	M+	M+	M	M	M	M	M
Ca**	..	L+	L	L	L+	L+	M—	M+	M+	M+	M+	H	H	H—	M	M
Mn*** (ppm.)	..	<1	6	11	<1	<1	<1	5	10	<1	<1	<1	3	<1	<1	<1
Al**** (ppm.)	..	Trace	Trace	Trace	1.0	2.0	Trace	Trace	Trace	0.8	1.5	Trace	Trace	0.5	1.0	1.0

Date Sampled 15/8/45 ("Middle" Mature Leaves).

PO ₄ '''	..	H—	H—	M+	M	H+	H	H	M+	M	H	H—	H—	M+	M
Ca**	..	L	L	L+	L	M—	M	M+	M	L	H	H+	H+	H	H
Mn*** (ppm.)	..	0.8	7	0.5	0.5	0.8	7	15	0.5	0.5	0.5	2	5	0.5	0.5
Al****	..														

Not Detectable Not Detectable Not Detectable

H = High M = Medium L = Low Figures in parts per million in standard extract (13)

(with sulphonated lorol as a wetting agent) was "painted" on to two of three leaflets of young chlorotic and older mottled "sprays" when the symptoms were in an early stage. (The third leaflet was used as a control to detect even a slight response.) The experiment was performed for each calcium level and the painting was repeated after an interval of a week.

No response to the ferric citrate was observed in any of these experiments. This result, together with the fact that the symptoms were not of the true iron chlorosis type (the fine veins were obliterated instead of remaining distinct and green) suggests that these symptoms of manganese toxicity in runner bean are not due to an induced iron deficiency. No symptoms in any way resembling iron chlorosis were observed in the cauliflower as a result of manganese toxicity. These results for the excess manganese treatments suggest that manganese toxicity in acid soils produces effects which are distinct from those due to iron deficiency. Since the symptoms are also dissimilar from those due to other known mineral deficiencies it seems possible that they are "direct" manganese toxicity effects.

SUMMARY.

1. A preliminary sand culture experiment with cauliflower and runner bean was set up to elucidate some of the problems of soil acidity and a series of crops was also grown in an acid soil in pots for purposes of comparison.

2. The typical symptoms produced in these crops in acid soils were reproduced in sand culture by supplying manganese at 12-25 ppm. with a low calcium level. These two crops showed widely differing types of symptoms for identical treatments.

3. Increasing calcium supply reduced the severity of manganese toxicity symptoms and also reduced the accumulation of "soluble" manganese as shown by tissue tests on the petioles.

4. Attempts to produce aluminium toxicity resulted in the appearance of symptoms suggestive of low phosphate status in the runner bean but not in the cauliflower.

5. Calcium level had an effect on aluminium accumulation early in the season which was similar to that on manganese. Aluminium accumulation was, however, very slight and the extractable aluminium was not detectable late in the season at a time when the resemblance to phosphorus deficiency in the beans was most marked.

6. The effects of excess manganese differed from those reported for other plants in culture solutions, where iron chlorosis has been induced, and it is suggested that the symptoms may be direct toxicity effects.

7. The crops in the acid soil showed a variety of deficiency symptoms, including those of nitrogen, phosphorus, calcium, magnesium and potassium; tissue tests showed that excess manganese had been accumulated.

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The tissue test on the sand culture material were carried out in collaboration with Mr. D. J. D. Nicholas.

REFERENCES.

- (1) HEWITT, E. J. (1943). *Ann. Rept. Long Ashton Research Station*, p. 31.
- (2) HEWITT, E. J. (1944). *Ann. Rept. Long Ashton Research Station*, p. 50.
- (3) HEWITT, E. J. (1945). *Ann. Rept. Long Ashton Research Station*, p. 44

- (4) WALLACE, T. (1943-44). "Mineral Deficiencies in Plants." *A colour atlas and guide (with supplement)*. H.M.S.O., London.
- (5) McCALL, A. G. and HAAG, J. R. (1921). *Soil Science*, 12; 67.
- (6) ARNON, D. I. and JOHNSON, C. M. (1942). *Plant Physiol.* 17; 525.
- (7) WALLACE, T., HEWITT, E. J. and NICHOLAS, D. J. D. (1945). *Nature*, 156; 778.
- (8) RAYNER, M. C. and NELSON JONES, W. (1944). "Problems in Tree Nutrition." Faber & Faber, London.
- (9) DAVIES, E. B. (1945). *Nature*, 156; 392.
- (10) ANDERSON, A. J. (1942). *J. Austral. Inst. Agri. Sci.*, 8; 73.
- (11) STEPHENS, O. G. and OERTEL, A. C. (1943). *J. Austral. Council Sci. and Indust. Res.* 16; No. 3, p. 69.
- (12) FRICKE, E. F. (1944). *Tasmanian J. Agric.* 15; 65.
- (13) NICHOLAS, D. J. D. and JONES, J. O. (1944). *Ann. Rept. Long Ashton Res. Station*, p. 84.
- (14) WRIGHT, K. (1943). *Plant Physiol.* 18; 708.
- (15) SOMERS, I. I., GILBERT, S. G. and SHIVE, J. W. (1942). *Plant Physiol.* 17; 317.
- (16) PEARSE, H. L. (1944). *Farming in South Africa*, 19; 688.

THE APPLICATION OF RAPID CHEMICAL TESTS IN THE DIAGNOSIS OF MINERAL DEFICIENCIES IN POTATO PLANTS.

By D. J. D. NICHOLAS.

The tissue test method (7) has been successfully used to diagnose mineral deficiencies in a variety of crop plants, but its general use as a method of recording nutrient deficiencies in plants growing on a wide variety of soil types requires further examination. Use was therefore made during 1945 of potatoes growing at four centres under various manurial treatments. These provided an excellent opportunity of testing the tissue test technique on the same crop plant growing on different soil types and under varied manurial treatments. The results obtained suggest that irrespective of soil type the tissues test standards fixed for K, Mg, Ca, PO_4 and NO_3 in potato are valid. The results in most instances reflect the manurial treatment and are in accord with results of the visual diagnosis method.

Experimental.

Plant Material Tested.

In Table I are listed the location, soil type and nutritional problem occurring at the four centres used. The dates of sampling for tissue tests are also included.

Field Sampling Methods. Random leaf samples were taken from a given treatment. The mid-stem position was used throughout as the physiological basis for sampling. The leaves sampled were thus likely to be comparable in size and metabolic activity. The interval between sampling and subsequent chemical testing of plant material was reduced to a minimum. Leaves visibly affected by virus, fungi or insect pests were avoided. Leaves showing visual signs of a nutrient deficiency were however included as part of the test sample.

Preparation of Test Samples. In all instances the potato petiole was taken for the extraction of the easily soluble nutrients. The petioles were cut up into approximately 2 mm. discs using a sharp scalpel. The standard units recommended in the initial report (7, 8) were adopted and 0.5 gm. was taken for each chemical test.

TABLE I.

Centre and Date of sampling.	Soil type	Potato variety	Nutritional problem
A1. Long Ashton Plot 17A 3 samplings 2/7/45 25/7/45 23/8/45	Drift over Keuper marl	Majestic	K, Mg, N and trace P deficiencies
A2. Long Ashton Plot 12 2 samplings 4/7/45 3/8/45	„	Kerr's Pink	K, Mg, N, P deficiencies. Chloride damage
B. Moreton-in-Marsh, Gloucester 2 samplings 30/7/45 2/9/45	Oolitic limestone soil	Majestic	K deficiency
C. Sutton Park, Birmingham 1 sampling 17/8/45	Gravelly sand, pod- solised Bunter pebble beds and glacial sand and gravel	Majestic	“Acidity” Ca defi- ciency. Mn toxic: Problems associated with reclaimed acid heathland, e.g. K, Mg & P deficiencies

Extraction. The soluble cell sap nutrients were extracted for 15 mins. as suggested in the initial report (7, 8).

Morgan's reagent (glacial acetic acid buffered by sodium acetate to a pH of 4.8) was used for the extraction of the following cations and anions—K, Mg, Ca, PO_4 , NO_3 , Cl and Mn (present in excess). Bulk extracts were made of 3 gm. of petiole material using 30 ml. of Morgan's reagent. Each chemical test was carried out in a clean specimen tube using 5 ml. of extract.

Chemical Tests used. The chemical methods used in testing the listed mineral elements are given in previous papers (7, 8).

Results.

The assessment of turbidity and colour was made initially by eye. The following categories were adopted: High (H), Medium (M), Low (L). These categories were further sub-divided by the use of + and — signs. In all instances the actual concentration of the nutrient in the 5 ml. Morgan's tissue extract was obtained either by using the Lovibond comparator and discs (Mg , PO_4 and NO_3) or comparing with prepared standards (K, Ca and Mn). The visual marking agreed well with the actual concentration of nutrient present. In Table II are listed the parts per million equivalents corresponding to the category markings for K, Mg, Ca, PO_4 and NO_3 .

In some instances the manganese and chloride levels in the 5 ml. Morgan's tissue extract are very high. The relation between the visual groupings and the parts per million values in the 5 ml. extract for Mn and Cl are given in Table III.

A healthy potato usually shows a Trace or Trace + (0.2—0.5 p.p.m. Mn) in the tissue extract, but when plants grow under acid conditions the easily soluble manganese is of the order of 3 to 10 p.p.m. (15).

A normal potato has about M to M+ i.e. 10—15 p.p.m. Cl in the 5 ml. Morgan's extract, whereas when heavy chloride manuring is given Cl can increase in petiole extracts to over 100 p.p.m. At this level visual signs of chloride damage are evident on the foliage.

The results are tabulated so as to show readily the correlations between tissue test data and (a) manurial treatment, (b) visual diagnosis data, (c) results for complete chemical analysis of the leaves.

TABLE II.
TISSUE TEST CATEGORIES AND CORRESPONDING NUTRIENT CONCENTRATION (P.P.M.)
IN 5 ML. MORGAN'S EXTRACT.

Visual Categories	Potassium	Magnesium	Calcium	Phosphate	Nitrate
H	150	10—11	200	30	15
H—	125	8—9	165	25	12.5
M+	100	6—7	130	20	10
M	75	5	95	15	7.5
M—	50	4	60	10	5
L+	25	3	25	5	2.5
L	< 25	2	10	< 5	0.1
L—	< 25	1	< 10	< 5	< 0.1

TABLE III.
A SUGGESTED RELATION BETWEEN VISUAL TISSUE TEST GROUPINGS AND CONCENTRATION
OF MN AND CL IN PARTS PER MILLION IN THE 5 ML. MORGAN'S EXTRACT.

Visual Groupings	H++	H+	H	H—	M+	M	Trace++	Trace+	Trace
Mn	5	3	2	1	—	—	0.8	0.5	0.2
Cl	100	75	50	25	15	10	—	—	—

Centre A.

Experiment 1.

In this experiment the following manurial treatments are represented: nil, farmyard manure, complete fertiliser (N.P.K.) omit nitrogen (P.K.), omit phosphorus (N.K.), omit potassium (N.P.). The rates of application per acre were as follows:—

F.Y.M.	..	10 tons per acre.
Nitrogen	..	4 cwts. of nitrate of soda per acre.
Phosphorus	..	3 cwts. of superphosphate per acre.
Potassium	..	3 cwts. of sulphate of potash per acre.

The treatments occur in triplicate and magnesium sulphate at 4 cwts. per acre is applied to one Block (II).

Tissue tests were carried out on 2/7/45, 27/7/45 and 23/8/45 on variety Majestic growing under various manurial treatments. Full chemical analyses were also carried out on the leaf laminae on the same dates. The results are reported in Tables IV—VI.

TABLE IV
A COMPARISON BETWEEN TISSUE TEST DATA AND COMPLETE CHEMICAL ANALYSIS

CENTRE AL.
1st Sampling Date 2/7/45

Nutrient Tested	Block I						Block II*						Block III					
	A Nil	B F.Y.M.	C N.P.K.	D Omit N	E Omit P	F Omit K	A Nil	B F.Y.M.	C N.P.K.	D Omit N	E Omit P	F Omit K	A Nil	B F.Y.M.	C N.P.K.	D Omit N	E Omit P	F Omit K
K	Tissue Test results	M	H—	H	H—	L+	M	H	H—	H	H	L	M	H—	H	H	H	L+
	Chemical Analysis K ₂ O % D.M.	3.42	4.60	6.09	4.69	2.50	3.48	6.36	5.76	6.85	6.83	1.57	4.26	5.41	6.32	7.51	6.48	2.60
Mg	Tissue Test results	H	H	M	H—	H	H	H	H	M+	M+	H	H	H	H	M—	H	H
	Chemical Analysis MgO % D.M.	1.29	1.00	0.55	0.86	1.25	1.18	1.29	1.72	0.62	0.83	0.96	1.18	1.42	1.41	0.58	0.99	1.03
Ca	Tissue Test results	H—	M+	M+	M+	H	H—	M+	M+	M+	M+	H	H—	M+	M+	M+	M+	H—
	Chemical Analysis CaO % D.M.	6.05	4.66	5.04	5.19	6.90	6.40	4.33	4.89	5.01	5.00	6.91	5.55	4.50	4.46	4.90	5.17	5.20
P	Tissue Test results	M+	H—	H—	M—	M+	M+	H	H—	M+	M	H—	M+	H—	M+	M+	M	M+
	Chemical Analysis P ₂ O ₅ % D.M.	0.78	1.02	0.93	0.50	0.74	0.76	1.39	1.24	0.86	0.59	1.09	0.82	1.11	0.90	0.84	0.65	0.78
NO ₃	Tissue Test results	M+	H—	M—	M+	H—	M+	H—	H—	M—	M	M+	M+	H—	H—	M—	H—	H

* MgSO₄ applied to all plots in Block II.

TABLE V.
A COMPARISON BETWEEN TISSUE TEST DATA AND COMPLETE CHEMICAL ANALYSIS.

CENTRE, AL.
2nd Sampling Date 27/7/45

Nutrient Tested	Block I						Block II*						Block III					
	A Nil	B F.Y.M.	C N.P.K.	D Omit N	E Omit P	F Omit K	A Nil	B F.Y.M.	C N.P.K.	D Omit N	E Omit P	F Omit K	A Nil	B F.Y.M.	C N.P.K.	D Omit N	E Omit P	F Omit K
K	Tissue Test results	L—	M	M+	H—	L—	L—	M+	M+	M+	H—	L—	L—	M	M	H—	H—	L—
	Chemical Analysis K ₂ O % D.M.	1.02	3.90	4.78	4.80	5.87	1.22	4.97	4.73	4.88	6.03	1.13	0.92	4.25	4.95	6.06	5.66	1.09
Mg	Tissue Test results	H	H—	M+	M—	M+	H—	H	H—	H—	M+	H	H—	H—	H—	M—	H—	H—
	Chemical Analysis MgO % D.M.	1.70	1.00	0.82	0.37	0.80	0.90	1.06	1.35	0.98	0.80	2.04	0.94	0.90	0.92	0.42	0.97	1.05
Ca	Tissue Test results	H+	H	M+	H—	H+	H+	H—	M+	H—	M+	H+	H+	H—	H—	M+	H—	H+
	Chemical Analysis CaO % D.M.	7.14	6.59	5.57	4.31	5.95	8.61	6.97	4.90	5.25	4.82	7.33	7.88	5.34	4.92	4.08	4.96	8.04
P	Tissue Test results	H—	M+	M+	M—	H	M+	M+	M+	M+	M—	H—	H—	M+	M+	H—	M—	H—
	Chemical Analysis P ₂ O ₅ % D.M.	0.96	0.78	0.90	0.90	0.53	1.36	0.82	0.90	0.88	0.56	1.20	1.23	0.82	0.89	1.11	0.55	0.93
NO ₃	Tissue Test results	M+	M+	M+	L	M+	H	M+	M+	L	M+	H	M+	M+	M+	L	M+	H—

* MgSO₄ applied to all plots in Block II.

TABLE VI.
A COMPARISON BETWEEN TISSUE TEST DATA AND COMPLETE CHEMICAL ANALYSIS.

CENTRE AL.
3rd Sampling Date 23/8/45

Nutrient Tested	Block I						Block II*						Block III					
	A Nil	B F.Y.M.	C N.P.K.	D Omit N	E Omit P	F Omit K	A Nil	B F.Y.M.	C N.P.K.	D Omit N	E Omit P	F Omit K	A Nil	B F.Y.M.	C N.P.K.	D Omit N	E Omit P	F Omit K
K	Tissue Test results	Nil	H—	M+	H—	Nil	Nil	M+	M	M	M+	Nil	Nil	M+	H—	H—	H—	Nil
	Chemical Analysis K ₂ O % D.M.	4.65	5.92	4.62	5.27			4.62	3.18	3.12	4.71			4.10	5.17	5.31	5.49	
Mg	Tissue Test results	H—	M+	L+	M	H	H—	H—	H—	M+	H—	H—	H—	M	M	L	M	H—
	Chemical Analysis MgO % D.M.		0.76	0.71	0.37	0.60		0.82	1.04	0.71	1.11			0.58	0.59	0.30	0.58	
Ca	Tissue Test results	H	H—	H—	H—	H	H	H—	H—	H—	H—	H	H—	H—	H—	H—	H	H
	Chemical Analysis CaO % D.M.		5.75	5.84	5.26	5.77		5.46	5.35	5.60	5.86			6.12	5.29	5.47	6.45	
P	Tissue Test results	M+	M	M+	M—	M+	M+	M+	M+	M+	L+	L+	M+	M+	M+	M+	M—	M—
	Chemical Analysis P ₂ O ₅ % D.M.		0.78	0.65	0.71	0.53		0.80	0.87	0.68	0.37			0.70	0.74	0.78	0.53	
NO ₃	Tissue Test results	M—	L+	Nil	M—	M—	M—	L+	L+	Nil	M—	M	M—	L+	M—	Nil	L+	M—

* MgSO₄ applied to all plots in Block II.

Tissue Test Values in Relation to Manurial Treatment.

In considering these relationships it should be mentioned that the soil has been under intensive cultivation in the past and contains approximately 5% of carbonate of lime in the surface soil as well as an adequate supply of organic matter. Previous susceptible crops have shown severe deficiency of potash and less acute deficiencies of nitrogen and phosphorus. Magnesium deficiency is also liable to occur in crops and for this reason Block II has been given a special dressing of magnesium sulphate at the rate of 4 cwts. per acre.

Potassium. At the three sampling times there is a significant difference between the potassium level in the N.P.K. plants and the omit K and nil plants. At later sampling dates these differences are more marked.

Magnesium. The values for Mg in samples from Block II are usually higher than those of Blocks I and III. This is in agreement with the soil treatment as Block II has received $MgSO_4$ at the rate of 4 cwt. per acre. The low N plants invariably have a lower Mg tissue test result when compared with other plants and these differences become more marked as the season progresses.

Calcium. In all instances the calcium tissue levels are adequate. This is to be expected as all plots irrespective of treatment have a 5% lime content. Calcium values are higher when potash is omitted from the manurial dressing.

Phosphate. The N.P.K. treated plants have an adequate phosphate content throughout the season, whereas the omit P plants record low tissue test values towards the end of the season. These results corroborate the manurial treatment.

Nitrate. Tissue test values for nitrate reflect the N soil application, at the first and second sampling dates. At the third sampling time, however, even the treated N plants record low values for NO_3 . In this instance, after 25/7/45 the nitrate test cannot be accepted as an indicator of total N status in the potato. When potash is not applied the nitrate values are higher in the tissues.

Tissue Tests in Relation to Visual Symptoms.

At this centre susceptible crops growing without a potash supply soon show visual signs of the deficiency. These become so severe that plants die back. Nitrogen deficiency, although not so severe as potash deficiency, has been observed. Magnesium deficiency also occurs especially in Blocks I and III, but is absent from Block II treated with magnesium sulphate. No definite symptoms of phosphate deficiency have as yet been recorded.

The incidence of the visual deficiency symptoms observed in Majestic during 1945 were as follows: K (severe), N (med.), Mg (slight), P (doubtful trace). In all instances the tissue test values corroborate the visual signs. Tables VII and VIII show the relation between the incidence of potassium and

TABLE VII.
THE RELATION BETWEEN THE INCIDENCE OF K DEFICIENCY (% AFFECTED PLANTS) AND
TISSUE TEST VALUES FOR K AT VARIOUS SAMPLING TIMES.

Manurial Treatment	Nil		F.Y.M.		N.P.K.		Omit N		Omit P		Omit K	
Sampling Date	% K defic.	K Tissue Test	% K defic.	K.T. T.	% K defic.	K.T. T.	% K defic.	K.T. T.	% K defic.	K.T. T.	% K defic.	K.T. T.
18th June, 1945	Nil	M+	Nil	H	Nil	H	Nil	H	Nil	H	Nil	M
2nd July, 1945	Nil	M	Nil	H—	Nil	H—	Nil	H	Nil	H—	48%	L+
13th Aug., 1945	100%	Nil	Nil	M+	Nil	M+	Nil	M+	Nil	M+	100%	Nil

magnesium deficiencies and the tissue test results at the three sampling dates.

It will be noted that the severity of K deficiency is related to the tissue test results for K and that this deficiency is very severe from mid to late season.

TABLE VIII.
THE RELATION BETWEEN THE INCIDENCE OF MG DEFICIENCY (% AFFECTED PLANTS) AND
TISSUE TEST RESULTS FOR MG AT VARIOUS SAMPLING INTERVALS.

Manurial Treatment	Nil			F.Y.M.		N.P.K.		Omit N.		Omit P.		Omit K.	
	Block No.	% Mg defic.	Mg T. T.	% Mg defic.	Mg T. T.	% Mg defic.	Mg T. T.	% Mg defic.	Mg T. T.	% Mg defic.	Mg T. T.	% Mg defic.	Mg T. T.
2nd July 1945	I II*	Nil Nil	H H	Nil Nil	H H	Nil Nil	H H	Nil Nil	M M+	Nil Nil	H— M+	Nil Nil	H H
16th July 1945	I II*	Nil Nil	H H	Nil Nil	M+ H—	Nil Nil	H H—	30% Nil	L+ H—	Nil Nil	M+ H	Nil Nil	H H
13th Aug., 1945	I II*	Nil Nil	H H—	Nil Nil	M+ H—	Nil Nil	M+ H—	45% Nil	L+ M+	Nil Nil	M+ H—	Nil Nil	H H

* MgSO_4 applied to Block II at rate of 4 cwts. per acre.

Visual symptoms of Mg deficiency were first observed in the omit N plots on 16th July. The tissue test value L+ agrees with the visual diagnosis. The absence of visual signs of this deficiency in Block II is due to the soil application of MgSO_4 and tissue test values are consistently higher.

Phosphate. Late in the season visual signs of P deficiency were noted in plants growing under depleted phosphate conditions. The tissue test value for PO_4 is L+, corroborating the visual diagnosis.

Nitrate. Visual symptoms of N deficiency were noted in potato (treatment P.K.) early in the growing season. The tissue test values at L agree with this observation. It was found that the nitrate values did not differentiate the nitrogen status at the third sampling 23/8/45. Even in N treated plants the nitrate results in tissue extracts were low. At this time the visual technique is better for diagnostic purposes.

Tissue Tests in Relation to Full Chemical Analysis.

Tissue test data for K, Mg, Ca, PO_4 and NO_3 appear in Tables IV—VI. It will also be noted that the full chemical analysis of the leaves are also given. The latter are reported as the oxides on a % dry matter basis. No data were obtained for total nitrogen.

In general there is a good correlation between the two chemical methods. Fig. 1 illustrates the measure of agreement which in most instances is close. There is a linear relation between the total and the easily soluble nutrients.

Experiment 2.

The following manurial treatments were given, Farmyard manure, complete fertiliser (N.P.K.), omit N (P.K.), omit P (N.K.), omit K (N.P.), omit P.K. (N); complete fertiliser (N.P.KCl), complete fertiliser (N.P.NaCl). The rates of application per acre were as follows:—

F.Y.M.	..	10 tons per acre.
Nitrogen	..	3 cwts. of sulphate of ammonia per acre.
Phosphorus	..	6 cwts. of superphosphate.
Potassium	..	2 cwts. of sulphate of potash.
Potassium	..	2 cwts. of muriate of potash.
Salt	..	2 cwts. of sodium chloride.

Tissue tests were conducted on Kerr's Pink from the various manurial plots on 4/7/45 and 3/8/45. The results are given in Tables IX and X.

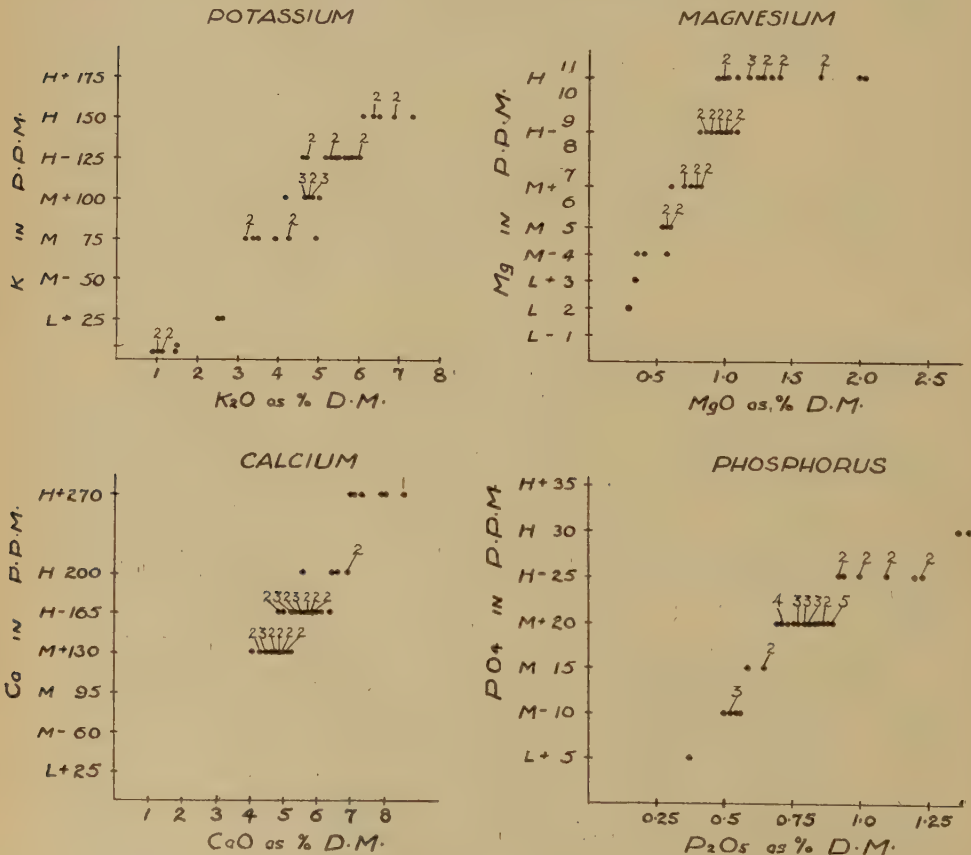
Tissue Tests in Relation to Manurial Treatment.

The soil is less highly cultivated than in Experiment 1, and contains trace carbonate of lime; the organic matter is typical of an arable soil. The salt *versus* muriate of potash plots (Nos. 1 to 6) form a separate block, as the soil is heavier than on other plots. The treatments have been given since 1923 except the salt and muriate plots which date from 1940. The pH of the soil is approximately 7.2. Deficiencies of N, K, P and Mg have been noted in special crops grown on these plots.

Potassium. At the first sampling date the N only and N.P. plants had a M value as compared with H— to H in treated potash plants. The difference between treated and omit K plants was highly significant on 3rd August when the former are at M+ or H. and the latter L— or nil. The K results for N.P.KCl and N.P.NaCl potato were alike at both dates.

Magnesium. The effects of nitrogen and potash manuring on the Mg

FIG. I.—THE RELATION BETWEEN TISSUE TEST VALUES AND FULL CHEMICAL ANALYSIS FOR K, Mg, Ca, PO_4 IN MAJESTIC.



Tissue Test results for the 3 sampling dates 2/7/45, 27/7/45, 23/8/45 Tables IV—VI are plotted, irrespective of treatment, against the full chemical data on leaf material.

(Figs. above points indicate the number of times values coincide at that interval).

TABLE X.

CENTRE A. Expt. 2.

TISSUE TEST RESULTS FOR K, Mg, Ca, PO_4 , NO_3 AND Cl IN KERE'S PINK GROWING UNDER VARIOUS MANURIAL TREATMENTS.

2nd Sampling Date, 3rd August, 1945.

Treatments and Plot Numbers.

Nutrient Tested	N (omit P.K.)			N.P.K.			P.K. (omit N.)			N.K. (omit P.)			N.P. (omit K.)			F.Y.M.			N.P.KCl.			N.P.NaCl.		
	J1	J2	J3	K1	K2	K3	L1	L2	L3	M1	M2	M3	N1	N2	N3	01	02	03	1	3	5	2	4	6
K	L	L	M—	H—	M+	H—	H—	M+	M+	H—	M+	M+	Nil	L+	Nil	M+	M	M+	M+	H—	H—	M+	H—	H—
Mg	H	H	H—	L+	L+	L+	L—	L—	L—	H—	M+	M+	H—	H—	H—	M	M—	M	M+	M+	H—	M+	M+	M+
Ca	H—	H—	H—	M+	M+	M+	M+	M+	M+	M+	H—	M+	H	H	H—	M+	M+	M+	M+	M+	H—	M+	M+	M+
PO ₄	M—	M—	M—	M+	M+	M+	H—	M+	M+	L+	M—	M—	H	M+	H—	M+	H—	M+	M+	M+	H—	M+	M+	M+
NO ₃	M+	H—	H	M+	M+	M+	L	L	L	M+	M	M	H—	M+	M+	M—	L+	L+	M	M	M	M	M	M
Cl	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	H+	H+	H+	H++	H++	H++

values are as for Experiment 1, being as follows: (1) when N is omitted the Mg is lower than when N is applied, (2) when K is omitted the Mg is higher than when K is given. Differences in Mg levels are significant at the second sampling time in the omit N plants at L—, N.P.K. treated at L+, N treated at H. The results suggest that Mg deficiency is more severe in omit N plots. The plants treated with F.Y.M. record a M value possibly due to insufficient nitrogen. There is no difference in the Mg status under differential chloride treatments.

Calcium. The soil has a trace carbonate of lime and a pH of 7.2. In all instances the Ca results are adequate at M+.

Phosphate. When phosphate is withheld values are lower than when applied. The mean values for the N.K. plants are M and L+ respectively, for the two sampling dates. Plants treated with N.K. have lower values than those receiving N only. Phosphate content of Cl treated plants is adequate throughout.

Nitrate. On 4th July the P.K. plants have a L+ value, whereas treated N record H—. The F.Y.M. plants are lower (M) than those of the N.P.K. treatment, and this difference is maintained in the 2nd sampling and suggests that nitrogen is a limiting factor in F.Y.M. manuring.

The nitrate content of N.P.KCl and N.P.NaCl treated material is adequate.

Chloride. The chloride treatments are clearly reflected. On the 4th July the N.P.KCl and N.P.NaCl plants have a mean value of H—as compared with N.P.K₂SO₄ plants at M. On 3rd August the chloride treated plants have high values, and at this stage visual symptoms of chloride damage were noted. The mean NaCl treatment is H++ and the K.Cl treatment H+, whereas the K₂SO₄ treatment remains at M.

Tissue Tests in Relation to Visual Symptoms.

Visual signs of N and K deficiencies were the most severe recorded at this trial, and Mg deficiency was also noted especially when N was omitted or K applied. Leaf symptoms characteristic of phosphate deficiency did not develop, but the spindly growth habit and dark green leaf colour was typical. Late in the season the omit P plants were green and no signs of leaf breakdown were detected.

Potassium. Visual symptoms appeared in mid June, in the omit K plants and later in the nil plots. The tissue test results for K fell as the season progressed. This agrees with the severity of this deficiency as assessed by the visual technique. At the later sampling date, 3rd August, the haulms were severely affected with dark marginal scorch of K deficiency when no soluble K could be detected in the tissues.

Magnesium. This deficiency was particularly severe in the low N plots, appearing in late June, later in N.P.K. plots, and then in F.Y.M. plots. At both dates of sampling the tissue test results agree with the severity of the visual signs. Thus on 3rd August the low N plants record L—; N.P.K. plants; L+ and F.Y.M., M—. No signs of Mg deficiency were reported from the omit K or N only plots, and Mg values at H and H— accord with these observations. A higher Mg status in the omit K potato may be ascribed to the low K level, as the latter when present at high concentrations accentuates the severity of Mg deficiency.

Phosphorus. Plants growing without phosphatic manuring were typically thin and spindly and the leaf was dark green. No sign of leaf breakdown

was observed. Chemical values for phosphate confirm these findings as on 4th July, N and N.K. treated plants have a mean value of M and at the later sampling, M—. Although this value is near the threshold of deficiency for the nutrient it is not as low as the K level in omit K plants. The phosphate results for plants treated with N.P.KCl and N.P.NaCl are adequate.

Nitrogen. Severe visual symptoms of N deficiency were observed in the P.K. treatment and slight pale leaf effects in the F.Y.M. plots. The chemical values confirm that the nitrate is low in P.K. treatment and also in the dung plots. When potash is omitted (N.P.) the nitrate values are higher than when K is applied. The nitrogen application is reflected at both sampling times. There is no difference in NO_3 content of N.P.KCl or N.P.NaCl plants and in all instances the values are adequate.

Chloride. Visual signs of chloride damage (brown edge scorch) were observed in the NaCl and KCl treated plants in late July. At the initial sampling time, although the Cl results are H and M+ as compared with M in the omit chloride plants, no visual symptoms were noted. On 3rd August the NaCl and KCl plants had H++ and H+ values respectively. This level produced toxic effects.

Centre B.

The soil at this centre is derived from oolitic limestone, contains approximately 10% lime and has a pH of 7.5. Various combinations of N.P.K. treatments were given and each of these were applied at two rates, viz. N1, N2, 2 cwt. and 4 cwt. of sulphate of ammonia respectively; P1 and P2, 3 cwt. and 6 cwt. of superphosphate respectively; K1 and K2, $1\frac{1}{2}$ cwt. and 3 cwt. of muriate of potash respectively. The 26 possible combinations are listed in Table XI. A nil plot was incorporated in the series.

Tissue tests were carried out at two sampling dates 30th July, 1945, and 2nd September, 1945. The results are given in Tables XI and XII.

The salient points are as follows:—

Potassium. At the initial sampling date tissue test results for the omit K potatoes (1-9) record M and M—. Although no visual signs of this deficiency were observed, these results are near the threshold of deficiency. The treated K plants vary from M+ to H— indicating an adequate level and thus reflecting the potash dressing. On 2nd September, it will be noted that the omit K plants have low tissue test values and in some instances (1-3, 5, 8, 9) K was not detected in the tissue extract. Severe visual symptoms of K deficiency were observed in these plots at that date. Potassium deficiency was particularly severe when N had been applied in the absence of potash (2, 3, 5, 6, 8, 9), and the chemical result for K in these plants is nil. Thus the severity of visual symptoms can be related to low tissue test values for K in the plant extract.

Magnesium. The magnesium level in the tissues is adequate at both sampling dates irrespective of treatment. No visual symptoms of this deficiency were recorded. There is a tendency for Mg values to be higher when K is omitted (1-9), but when N is not applied the Mg is slightly lower (10, 13, 16, 19, 22, 25).

Calcium. The soil in this area is oolitic in origin containing approximately 10% carbonate of lime with pH 7.5. This is reflected on Ca tissue test results, which are M+ and over, at the two sampling times. There is no marked increase in Ca in the omit K plants as in the previous two experiments.

Phosphate. On 2nd September, chemical values for PO_4 in the omit P plants (1-3, 10-12, 19-21) are M+ or M. At the later date plots 2, 10, 12

CENTRE B. 1st Sampling 30/7/45.

TABLE XI.

TISSUE TEST DATA FOR K, Mg, Ca, PO₄ AND NO₃ IN MAJESTIC GROWING UNDER VARIOUS MANURIAL TREATMENTS.

Treatment	Nil	N ₁	N ₂	P ₁	N ₁ P ₁	N ₂ P ₁	P ₂	N ₁ P ₂	N ₂ P ₂	K ₁	N ₁ K ₁	N ₂ K ₁	P ₁ K ₁	N ₁ P ₁ K ₁	N ₂ P ₁ K ₁	P ₂ K ₁	N ₁ P ₂ K ₁	N ₂ P ₂ K ₁	K ₂	N ₁ K ₂	N ₂ K ₂	P ₁ K ₂	N ₁ P ₁ K ₂	N ₂ P ₁ K ₂	P ₂ K ₂	N ₁ P ₁ K ₂	N ₂ P ₁ K ₂
Nutrient Tested	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
K	M—	M—	M	M—	M	M	M	M	M—	M+	M+	M+	H—	H—	H—	M+	M+	M+	M+	M+	H—	M+	H—	H—	M+	M+	H—
Mg	H	H	H	H	H	H—	H	H—	M+	H	H	H	M+	M+	H—	H—	H—	H—	H	H	H—	M+	M+	H—	M+	H	H—
Ca	M+	M+	M+	M+	M+	H	M+	H	H	M+	M+	M+	M+	H	H—	M+	M+	H—	M+	M+	M+	M+	M+	M+	M+	M+	M+
PO ₄	H—	M+	M	H—	M+	M+	H—	H	H	M+	M+	M+	M+	M+	H—	M+	H—	H—	M	M+	M+	M+	M+	M+	M+	M+	H—
NO ₃	M	H—	M+	M	M+	H	M	H—	H—	M	M+	H—	M	M+	H—	M	M+	H—	M	M	M+	M	M+	H—	M	M+	H—

CENTRE B. 2nd Sampling 2/9/45.

TABLE XII.

TISSUE TEST DATA FOR K, Mg, Ca, PO₄ AND NO₃ IN MAJESTIC GROWING UNDER VARIOUS MANURIAL TREATMENTS.

Treatment	Nil	N ₁	N ₂	P ₁	N ₁ P ₁	N ₂ P ₁	P ₂	N ₁ P ₂	N ₂ P ₂	K ₁	N ₁ K ₁	N ₂ K ₁	P ₁ K ₁	N ₁ P ₁ K ₁	N ₂ P ₁ K ₁	P ₂ K ₁	N ₁ P ₂ K ₁	N ₂ P ₂ K ₁	K ₂	N ₁ K ₂	N ₂ K ₂	P ₁ K ₂	N ₁ P ₁ K ₂	N ₂ P ₁ K ₂	P ₂ K ₂	N ₁ P ₁ K ₂	N ₂ P ₁ K ₂
Nutrient Tested	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
K	Nil	Nil	Nil	L+	Nil	L+	L	Nil	Nil	M	M+	M—	M—	M—	M—	M+	M	M—	M+	M	M+	M+	M+	M+	M+	M+	M+
Mg	H	H	H	H—	H—	H—	H—	H	H	H	M+	H	H—	H	H—	M+	M+	H—	M+	M+	M+	H—	M+	M+	H	M+	M+
Ca	M+	M+	M+	M+	M+	H—	M+	H—	H	M+	H	M+	M+	M+	M+	H	M+	M+	H	M+	M+	M+	M+	M+	M+	H—	H—
PO ₄	M—	M—	M	M	M+	M+	M+	M+	M+	M	M—	M	M	M	M	M	M+	M+	M—	M—	M—	M	M	M	M+	M+	M+
NO ₃	M	M+	H	M	M+	H—	M	M+	H—	M	M+	M+	M—	M	H—	M—	M+	H—	M—	M	H	M	M	M+	M—	M	H—

and 21 record M—, which approaches the threshold value for this deficiency. However, no visual signs of phosphate deficiency were observed. Tissue test results for phosphate in treated P plants vary from M+ to H at both sampling dates. Thus the phosphate soil application is confirmed by the chemical tests.

Nitrate. At the initial sampling time the nitrate test can be regarded as an indicator of the total N content of the plants. When N is omitted (1, 4, 7, 10, 13, 16, 19, 22 and 25) the NO_3 value is M, whereas when N is applied, especially at the N_2 level, values increase to H—. Later in the season the NO_3 level in some omit N plants (13 and 16) fall to M—, but in the treated N material the tissue values are maintained at H—. Although no visual symptoms of this deficiency were observed, tissue test results discern differences in NO_3 levels which are in the agreement with treatment.

Centre C.

The soil of this area is a highly podsolised gravelly sand, derived from glacial material from the Bunter Pebble Beds. The soil pH is approximately 3.9, and the natural vegetation was a typical heath with heather and *Nardus* grass dominant. The potato area had been reclaimed in 1944 when liming and fertiliser plots had been laid down to study the manurial needs of the soil.

The experimental area is divided into strips to which different rates of ground limestone had been applied in 1944 and across which various fertiliser treatments consisting of N.P.K. combinations are given annually. The rates of application of ground limestone and N.P.K. fertilisers are as follows:—

Ground Limestone at 3 and 9 tons per acre.

Nitrogen (N) as sulphate of ammonia at 3 cwts. per acre.

Phosphorus (P) as triple superphosphate at $2\frac{1}{2}$ cwts. per acre.

Potash (K) as muriate of potash at $2\frac{1}{2}$ cwts. per acre.

The ground limestone was applied in two ways: (1) as a surface application, (2) disced in and thoroughly mixed with the soil to a depth of 12 inches.

Comparative data for tissue tests, vigour markings for haulms, and visual symptoms are given in Tables XIII and XIV.

Liming is necessary before a crop can be grown successfully in this area. In the unlimed plots the few plants that survived showed acute "acidity" symptoms being squat and stunted. Recently it was reported (7, 15) that manganese tends to accumulate in plants growing under acid soil conditions. This accumulation may be such as to prove toxic giving rise to so-called "acidity" symptoms. Calcium deficiency is also a factor in the "acidity" complex.

Potassium, phosphate and to a lesser degree magnesium deficiencies have been noted in susceptible crops grown at this centre. Thus the various N.P.K. treatments provided an opportunity of studying the fertiliser needs of the soil. The visual data for Majestic are included in Tables XIII and XIV.

Crop Vigour in Relation to Tissue Tests and Visual Symptoms.

Crop vigour markings (based on level of a good crop) were made a week prior to tissue testing. These markings are given in Tables XIII and XIV. The maximum possible score for each plot is 10. Low markings are conditioned by (1) low Ca and high Mn chemical values in the non-limed plots, (2) low K values, e.g. plots 9, 14, 15, 16, 17, 23, 24. The vigour marking for Ca N.K. treated plants is 4 as compared with 10 for Ca N.P.K. plants. This emphasises the importance of phosphatic manuring in relation to haulm vigour. The visual symptoms of P deficiency were observed when phosphate

was not applied. It will be noted that although vigour marking and visual signs suggest phosphate deficiency the chemical value for phosphate is M. This is near the threshold of deficiency (M—), but there is no significant difference between N.P.K. plants and omit P plants.

In this instance the phosphate results barely reflect the phosphatic manuring and are not related to the incidence of phosphate deficiency.

The salient features arising out of Tables XIII and XIV are as follows :—

Potassium. When potash is omitted from the base dressing K tissue results vary from M— to Nil, whereas treated plants have a M+ to H range. Where visual symptoms of K deficiency were apparent tissue test values are below M—. This value thus appeared to be the threshold value for the deficiency and is in accord with results from other centres.

Magnesium. This deficiency occurred when K was included in the manurial treatment. Visual signs were evident when tissue test value fell to M— level. A high K status appears to accentuate the severity of Mg deficiency. The N effect on Mg noted in Centres A and B is not shown at this Centre.

Calcium. The pH of the unlimed strips is 3.9, denoting strongly acid conditions and a very low calcium status. In all instances visual signs of calcium deficiency were recorded from the unlimed plots, and these were absent from all plants on the limed areas. Tissue test results for Ca, at L and L+ (untreated) and M+ to H (treated) corroborate these observations. The tissue test data suggest that there is no difference between the 3 ton and 9 ton lime treatment when disced well into the soil, but the surface application appears to be less effective.

Phosphate. The phosphate contents appear to be adequate throughout. When it is omitted values are at M as compared with M+ or H— when applied. These differences are not significant and so the phosphatic manuring is not well reflected. Visual signs of P deficiency were noted and haulm vigour marking at 4 in N.K. plots confirm that phosphate was the limiting factor. Chemical values do not agree with the visual data. The tissue test method for determining phosphate in “acid” plants must be re-examined to establish whether the values accord with the total P content.

Manganese. It has been previously reported that manganese tends to accumulate in plants when growing under acid soil conditions (7, 15). This accumulation may be such as to prove toxic to the plants and give rise to so called “acidity” symptoms (15). The tissue test results for manganese in such plants are abnormally high as compared with those growing on soils near neutrality.

The tissue test results for manganese in the unlimed plants are very high (H+ to H++ 5 p.p.m.) and this high level probably produced toxic effects. Thus, although the visual signs were recorded as due to Ca deficiency excess manganese effects are doubtless also involved in the production of the “acidity” symptoms in the unlimed potatoes. When lime is applied the manganese level in the plants is reduced. The most effective treatment is the 9 tons (disced under) treatment, where Mn values fall to Tr++ (0.8 p.p.m.) corresponding to values for normal potato extracts. The lime treatment thus not only supplies the required Ca but also controls the intake of manganese by the plants.

In many of the unlimed plots a new visual symptom was observed in potato. This consisted of a brown necrosis and tinting around the main vein. Tissue tests results suggest that this results from from a combination of low calcium and an abnormally high manganese.

DISCUSSION.

The four Centres used for the potato manurial experiments differ widely in soil characters. Centres A1 and B are highly calcareous, pH 7.5; Centre A2 has a trace carbonate of lime pH 7.2; whereas Centre C is strongly acid pH 3.9.

At Centres A1 and A2 visual symptoms of N, K, P and Mg deficiencies were noted, and at A2 injurious effects of heavy chloride dressings were observed. Potash deficiency is the main problem at Centre B, whereas at Centre C, K, Mg, P and Ca deficiencies and manganese toxicity are the main nutritional disorders. It will be noted that K deficiency is common to the four centres; N at A1 and A2; Mg and mild P effects at A1, A2 and C.

At Centre A1 tissue tests reflect the manurial treatments at the three sampling dates, but differences between treated and non-treated plants are greater at the later sampling times. When a given constituent is not applied, *e.g.* N, P or K, the value for the mineral element is lower than in treated plants. In the N.P. treatment (omit K) higher values for N, Mg and Ca are recorded. The effects of P.K. treatment (omit N) on tissue results are (1) low NO_3 and (2) low Mg values. There is an increase in Mg level with (1) MgSO_4 soil application, (2) N manuring. At Centre A2 the chemical results agree with the soil treatment and the manurial effects mentioned for Centre A1 also occur. At Centre B the effects of N.P. manuring (omit K) and P.K. (omit N) on other nutrients noted at Centres A1 and A2 are absent. At Centre C the beneficial effects of adding potash and lime are confirmed, the latter by (1) increase in Ca and (2) decrease in Mn; but the P manuring is not always reflected by tissue values.

In the main, tissue test results agree with the visual data obtained at the four centres. For most mineral elements the M— to L+ category was regarded as the threshold of deficiency usually accompanied by visual signs. Symptoms of K, Mg, and N were readily confirmed, and the mild phosphate effects (no leaf breakdown) observed at Centre A1 and A2 were substantiated. At Centre C, however, although characteristic P deficiency symptoms were noted, the tissue test values were in some instances above the threshold of deficiency (M). Further work is essential to examine the applicability of the phosphate tissue test to plants growing in acid soil. At Centre C typical "acidity" symptoms were noted on the non-limed plots pH 3.9. Tissue test results confirm that calcium deficiency is involved, but the abnormally high manganese in the low Ca plants suggests that the trace element is present at toxic concentrations. A new visual symptom was observed in the unlimed plots, *viz.* a brown tinting and necrosis adjacent to the main vein and chemical data for Mn at H++ and Ca at L confirm that this symptom is due to Ca deficiency and Mn toxicity. Thus the tissue test method is of value in resolving two of the factors involved in the production of "acidity" symptoms in potato.

It will be noted that nutrient values can be near the threshold of deficiency or toxicity level before visual symptoms were observed. Tissue test results can therefore give a clue to an impending mineral disorder prior to the onset of visual signs. The nitrate result cannot be regarded as an index of N status late in the season as even in N treated plants the values fall to low levels. In this instance the visual method is more reliable.

Vigour markings (based on the level of a good crop) were made at Centre C. Low markings were associated with (1) low Ca and high Mn, (2) low K values. Full marks were awarded to the plots receiving lime and N.P.K. treatment. Vigour data confirm the visual symptoms in that P was the

limiting factor in the N.K. (omit P) treatment, but in some instances tissue test results do not agree with the visual assessment as the P level at M is not within the critical deficiency range.

At Centre A the full chemical data obtained on the foliage are in accord with the tissue test results. The trend and order of agreement is given in *Fig. 1*. In most instances the correlation between the two chemical methods for K, Mg, Ca and P are of a high order.

The tissue test standards for K, Mg, Ca, PO_4 , NO_3 and Mn fixed for High to Low range are valid for each of the four centres. This observation is important, as comparisons can be made between potato growing at centres markedly different in soil type.

SUMMARY.

1. Tissue test standards for K, Mg, Ca, PO_4 , NO_3 , Cl and Mn were applicable to potatoes growing under various manurial treatments at four centres which differ widely in soil characters.

2. In most instances the values reflected the manurial treatment and were a useful guide to the fertiliser needs of the plants.

3. The following manurial effects were observed : (a) plants treated with N.P. (omit K) had higher contents of Ca, Mg and NO_3 (all centres), (b) K.P. (omit N) depressed the Mg content (Centres A1 and A2), (c) Ca treatment decreased Mn values (Centre C).

4. The tissue test data confirmed the visual symptoms of K, Ca, N and P deficiencies as well as Mn and Cl toxicities. Visual signs of P deficiency noted at Centre C were not always corroborated by low PO_4 values.

5. The "acidity" symptoms at Centre C were due to a low Ca and an abnormally high Mn status and a new visual symptom in the unlimed plots could also be related to the two nutrient factors, viz. Ca deficiency and Mn toxicity.

6. Low vigour at Centre C was associated with (a) low Ca and high Mn levels, (b) low K values. In the N.K. (omit P) treatment although vigour and visual data agree in showing that P was the limiting factor, in some instances, PO_4 values at M were adequate.

7. Contrasts between plants receiving different treatments (Centres A1 and A2) were more pronounced as the season progressed. Values near the threshold of (a) deficiency or (b) toxicity level often gave a clue to an impending nutrient disorder prior to the appearance of symptoms. Tissue test NO_3 values cannot differentiate N treatments late in the season, and in this instance the visual method is more reliable.

8. Tissue test values were in accord with the full chemical analysis at the three sampling dates (Centre A).

9. The tissue test technique is of value as an early diagnostic method and is applicable to potato growing at centres differing widely in soil type.

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REFERENCES.

- (1) CAROLUS, R. L. (1938). The use of rapid chemical plant nutrient tests in fertiliser deficiency diagnosis. *Va. Truck Exp. St. Bul.* **98**.
- (2) EMMERT, E. M. (1934). Tests for phosphate, nitrate and soluble N in conducting tissue of tomato and lettuce plants. *Ky. Agr. Exp. Sta., Circ.* **43**.
- (3) FAWCETT, F. and STROUGHTON, R. (1944). *The chemical testing of plant nutrient solutions*. Tintometer, Salisbury, England.
- (4) HESTER, J. B. (1941). Soil and plant tests as aids in soil fertility programme. *Comm. Fertilisers Yearbook*.
- (5) HOFFER, J. B. (1930). Testing corn stalks chemically to aid in determining their food needs. *Purdue Univ., Bul.*, **298**.
- (6) MACY, P. (1936). Quantitative mineral requirements of plants. *Plant Physiol.*, **11**, 749.
- (7) NICHOLAS, D. J. D. and JONES, J. O. (1944). The application of rapid chemical tests to plant tissues in the diagnosis of deficiencies of mineral nutrients. *Long Ashton Agr. and Hort. Res. Stn. Rept.*, **84**.
- (8) NICHOLAS, D. J. D., JONES, J. O. and PLANT, W. (1944). The technique of chemical tissue tests. *Long Ashton Agr. and Hort. Res. Stn. Rept.*, **79**.
- (9) PAGE, N. R. and BURKHART, L. (1941). Extraction and distribution of soluble nutrients in the peanut plant. *Proc. Assoc. Soc., Agron.* **20**.
- (10) PEACH, M. and ENGLISH, L. (1944). Rapid microchemical soil tests. *Soil Sci.*, **57**, 3.
- (11) SCARSETH, G. D. (1942). Plant tissue testing in diagnosis of nutritional status of growing plants. *Soil Sci.*, **55**, 1.
- (12) THORNTON, S. F., CONNOR, S. D. and FRASER, R. R. (1939). Rapid chemical tests for soils and plants. *Purdue Univ., Circ.* **204**.
- (13) ULRICH, A. (1942). Potassium content of grape leaf petioles and blades contrasted with soil analysis. *Proc. Amer. Soc. Hort. Sci.*, **41**.
- (14) WALLACE, T. (1944). *The Diagnosis of Mineral Deficiencies in Plants by Visual Symptoms. A Colour Atlas and Guide*. H.M.S.O., London.
- (15) WALLACE, T., HEWITT, E. J. and NICHOLAS, D. J. D. (1945). Determination of factors injurious to plants in acid soils. *Nature*, **156**, 778.

EXPERIMENTS ON THE CONTROL OF MAGNESIUM DEFICIENCY IN GLASSHOUSE TOMATOES.

PROGRESS REPORT III.

By D. J. D. NICHOLAS, J. O. JONES and T. WALLACE.

Experiments on the control of magnesium deficiency in glasshouse tomatoes were continued in 1945. Four centres were used, of which three had been used in previous years, the fourth being added as magnesium deficiency was particularly severe in the 1944 crop.

In previous papers (1, 2) it has been shown that magnesium sulphate applied to the soil at various rates markedly reduces foliar symptoms. The most effective and economical control of the deficiency, however, was brought about by 2% foliage sprays applied at intervals throughout the growing season. In a few instances slight leaf damage resulted, but neither flower trusses nor yields were affected.

Experiments described in this report were designed (a) to check the results obtained during season 1944, (b) to determine the best strength of spray to effect control without causing damage, (c) to ascertain the minimum number of spray applications required to control the deficiency throughout the entire growing season.

The results obtained at the four centres are in agreement with those for 1944. A minimum of 10 cwts. per acre of magnesium sulphate* (calcined kieserite) used as a base dressing to the soil was required to produce a satis-

* The magnesium sulphate used for this experimental series was calcined kieserite ($\text{MgSO}_4 \cdot \text{H}_2\text{O}$) originally containing 30% MgO but at the time of experiment averaging approximately 20% MgO.

factory commercial control of the deficiency. A more effective control was obtained by using either a 2% or a 1% foliage spray at intervals throughout the season, using as little as $1\frac{1}{2}$ cwt. of this material. The data showed that early sprays arrested the onset of foliar symptoms but failed to control symptoms later in the season, and for this purpose spraying at intervals of three weeks to a late stage of growth was necessary. Two sprays early in the season were more effective than an early spray followed by an application late in the season. Both 2% and 1% sprays were equally effective in controlling the deficiency.

EXPERIMENTAL.

Centre I.

At this centre two trials were carried out. Experiment I was designed to compare effects of various rates of soil applications of magnesium sulphate in the base fertiliser and the application of liquid dressings of this material to the soil around the plant roots during growth, and secondly to compare the effectiveness of various rates of soil application and a foliage spray-treatment.

Experiment I.

For this experiment a house was divided into 8 plots in 2 blocks (A and B), and the following randomised treatments given in duplicate in addition to the grower's base dressing of N.P.K. : (1) No MgSO_4 , (2) MgSO_4 at 10 cwt. per acre as a base dressing, (3) MgSO_4 at 20 cwt. per acre as a base dressing, (4) 2% solution of MgSO_4 applied to the soil around the roots, twice during the growing season, making a total of 5 cwt. per acre.

The magnesium sulphate was applied to the soil in treatments 2 and 3 on 17/2/45. The house was planted with the variety Ailsa Craig on 21/3/45. Treatment 4 was applied on 26/3/45 and on 7/5/45, using a rate of $2\frac{1}{2}$ cwt. per acre on each occasion.

Observational Data. Counts of all plants showing visual signs of magnesium deficiency, irrespective of severity, were recorded for each plot at intervals, the numbers affected being expressed as percentages in Table I. Severity markings by plots were also made and these are also included in the table.

TABLE I.
PERCENTAGES OF MAGNESIUM DEFICIENT PLANTS AND SEVERITY MARKINGS.

Date	24/5/45		20/6/45	
Mg Treatment	Block A	Block B	Block A	Block B
Nil	56 : med.-severe	53 : med.-severe	83 : med.-severe	67 : med.-severe
10 cwt. per acre . .	25 : slight	28 : slight	37 : slight-med.	30 : slight-med.
20 cwt. per acre . .	9 : v. slight	14 : slight	22 : trace-v. slight	34 : slight
2% solution to soil	25 : slight	20 : slight	50 : med.	56 : med.

The application of magnesium sulphate either as a solid in the base dressing or in solution to the soil reduced the incidence of the deficiency. The 20 cwt. application gave the best control whilst the solution method was the least effective.

Chemical Data. Leaf samples were taken for analysis on 7/5/45 and 20/6/45. No visual symptoms were observed on the first sampling date. The chemical data are presented in Table II.

TABLE II.
MAGNESIUM CONTENT OF TOMATO.*

Date	Mg Treatments	Nil		10 cwt.		20 cwt.		Liquid to Roots	
	Block	A	B	A	B	A	B	A	B
7/5/45	MgO as % Dry Matter	0.61	0.54	0.87	0.69	1.08	0.91	0.61	0.50
20/6/45	"	0.33	0.40	0.50	0.57	0.64	0.68	0.41	0.42

The data agree well with the visual observations. At the first sampling date when no visual signs were observed the MgO figure for all samples is over 0.5% D.M. The treatments are clearly reflected. At the later date the superiority of the 10 and 20 cwt. base applications over the liquid treatment is evident.

Experiment 2.

This house was again divided into two blocks with four treatments in duplicate. The grower's N.P.K. dressing was applied throughout. The Mg treatments were as follows: (1) Nil, (2) 10 cwt. MgSO_4 per acre to soil, (3) 20 cwt. MgSO_4 per acre to soil, (4) 2% foliage spray at intervals throughout the season.

The magnesium sulphate in treatments 2 and 3 were applied on 17/3/45. The house was planted with Ailsa Craig on 20/3/45.

The foliage spray was applied with a stirrup pump using a fine spray nozzle. The wetting agent used was sulphonated lorol at the rate of 10 oz. per 100 gallons. In all five sprays were applied at intervals of three weeks throughout the growing season†, as listed below.

Date of spray application	Gall. per acre	Lb. MgSO_4 per acre	Weather conditions	Damage recorded
26/3/45	200	40	Sunny	Nil
13/4/45	300	60	Sunny	Nil
7/5/45	500	100	Sunny	Nil
24/5/45	500	100	Overcast dull	Trace tip leaf burn in 2 plants
18/6/45	500	100	Sunny	Nil

It will be noted that the total amount of MgSO_4 used for the five sprays is about $3\frac{1}{2}$ cwt. An interesting feature is that the only damage recorded occurred under dull conditions when the spray dried more slowly.

* Chemical data for K, Ca and P are available for all leaf samples but are not reported because no interaction effects with Mg were noted.

† To obviate possible damage from spray treatments in all experiments described in this paper a trial spray was always applied to a few plants 48 hours prior to the main application. This allows sufficient time for symptoms of injury to develop. This procedure should be followed where spraying is adopted as a commercial practice.

Observational Data. The incidence of the deficiency for two dates is given in Table II. The percentage affected plants as well as the severity marking for the deficiency are shown.

TABLE III.
PERCENTAGES OF MAGNESIUM DEFICIENT PLANTS AND SEVERITY MARKING.

Mg Treatment	24/5/45		20/6/45	
	Block A	Block B	Block A	Block B
Nil	35 : med.	20 : slight	100 : severe	81 : med.-severe
10 cwt.	2 : v. slight	4 : trace	40 : med.	40 : slight-med.
20 cwt.	3 : v. slight	2 : trace	30 : slight	20 : slight
2% foliage spray	Nil	Nil	1 : trace	Nil

The soil applications considerably reduced the incidence of magnesium deficiency, and the 20 cwt. treatment was superior to the 10 cwt. application. The foliage spray was much more effective than the soil treatments in preventing the onset of visual symptoms and was more economical in materials used, viz. $3\frac{1}{2}$ cwt. per acre for the season, as compared with 10 and 20 cwt. of MgSO_4 in the soil treatments.

Chemical Data. Leaf samples were taken from the mid stem portions of the plants. Results are given in Table IV for two sampling dates, viz. : 7/5/45 and 18/6/45. On the first date no visual signs of magnesium deficiency were apparent.

TABLE IV.
MAGNESIUM CONTENT OF TOMATO.

Date	Mg Treatment	Nil		10 cwt.		20 cwt.		2% foliage spray	
	Block	A	B	A	B	A	B	A	B
7/5/45	MgO as % Dry Matter	0.48	0.43	0.55	0.60	0.97	0.85	1.05	1.20
18/6/45	„	0.16	0.11	0.37	0.34	0.39	0.49	0.74	1.09

The chemical results for magnesium clearly reflect the treatments given and agree with the visual data. At the first sampling date the soil applications have been beneficial but the sprayed plants show the highest MgO value, 1.20% D.M. On 18/6/45 the magnesium content in the untreated plants had fallen to low values and those of the soil treated plants, although higher, are below the level of sufficiency. The sprayed plants had maintained a high magnesium content.

It should be noted that the MgO results for the sprayed plants may be too high because of the possibility of spray deposit on the leaf surface, but the absence of visual symptoms suggests that higher magnesium levels actually exist within the sprayed plants.

Centre II.

Three separate trials were carried out at this centre. The first was designed to test the effect of various rates of MgSO_4 applied as soil dressings.

In the second, soil treatments were compared with a 2% foliage spray, the latter applied at intervals of 3 weeks throughout the season. The third trial was as for 2, but the effect of varying the number of sprays applied during the season was studied.

Experiment 1.

The house was divided into six plots, the treatments in duplicate being as follows: (1) No magnesium sulphate, (2) magnesium sulphate at 10 cwt. per acre as a base dressing, (3) magnesium sulphate at 16 cwt. as a base dressing. During the previous year plot 2 had received 10 cwt. per acre of magnesium sulphate, whereas plot 3 had 4 cwt. Thus the totals for the two seasons for these plots was identical. This afforded an opportunity of studying any residual effect due to the previous season's treatment. The fertiliser was applied on 15/2/45 and the house planted to Vetomold on 6/3/45.

Observational Data. Three counts of the number of plants affected were made during the season. The data are given in Table V as percentages of the total numbers of plants per plot. A general severity marking for each plot is also included.

TABLE V.
PERCENTAGES OF MAGNESIUM DEFICIENT PLANTS AND SEVERITY MARKINGS.

Date	7/5/45		28/5/45		19/6/45	
MgSO ₄ Treatment	Block A	Block B	Block A	Block B	Block A	Block B
Nil	20 : med.	30 : med.	90 : severe	95 : severe	95 : v. severe	100 : v. severe
10 cwt.	6 : trace	8 : trace	38 : slight -med.	50 : slight -med.	64 : med.	56 : med.
16 cwt.	7 : trace	8 : trace	48 : slight -med.	46 : slight -med.	74 : med.	67 : med.

In the untreated plots the incidence of magnesium deficiency was very severe. Both soil treatments reduced (a) severity of foliar symptoms, (b) the number of plants affected. There does not appear to be any marked difference between the two rates of soil treatment in controlling the deficiency.

Chemical Data. The chemical results for leaves taken from the plots on 7/5/45 and 19/6/45 are presented in Table IV.

TABLE VI.
MAGNESIUM CONTENT OF TOMATO.

Date	Mg Treatments	Nil		10 cwt.		16 cwt.	
	Block	A	B	A	B	A	B
7/5/45	MgO as % Dry Matter	0.30	0.30	0.46	0.48	0.58	0.54
19/6/45	„	0.18	0.21	0.30	0.29	0.39	0.42

The magnesium content of the leaves irrespective of treatment falls as the season progresses. At the first sampling time the nil plants at 0.30%

were well below the threshold of deficiency, viz.: 0.50% MgO. The soil treatment was clearly reflected at the early date. On 19/6/45 the visual signs were very severe in the nil plots and the MgO content very low. The magnesium contents of treated plants, although higher than the control, were inadequate and this is corroborated by the visual data. The chemical results suggest that the 16 cwt. treatment 3 was better than the 10 cwt. treatment 2 although the total amounts applied to 2 and 3 over the two seasons were equal.

Experiment 2.

This house was divided into six plots. The treatments were in duplicate as follows: (1) nil, (2) 20 cwt. of magnesium sulphate as a base dressing, (3) 2% foliage spray applied five times, at intervals of three weeks, throughout the growing season. The grower's N.P.K. dressing was applied to all plots. The soil application in treatment 2 was applied on 26/2/45. The house was planted with Vetomold on 6/3/45.

The 2% spray was applied using the same spraying technique as for the previous centre. A spreader, sulphonated lorol was used in all instances at the rate of 10 oz. per 100 gall. Details of spray treatments are given below:—

Date of spray application	Gall. per acre	Lb. MgSO_4 per acre	Weather conditions	Damage recorded
28/3/45	150	30	Dull overcast	Very slight bronze lesions on few plants
18/4/45	300	60	Sunny	Nil
7/5/45	400	80	Sunny	Nil
28/5/45	400	80	Sunny	Nil
19/6/45	500	100	Sunny	Nil

It will be noted that the total amount of MgSO_4 used was only about 3½ cwt. for the five sprays. Slight leaf lesions were noted after initial spray but the flower trusses were undamaged. In this instance the slight damage occurred when spray was applied on a dull day and this agrees with observations at the previous centre.

In view of the slight damage recorded in the two plots after the initial spray, two rows only of each of the two spray plots received the five spray treatments. The remainder of the plants received no further spray treatment until 28/5/45, when a late spray was given to test whether such a treatment would arrest the development of deficiency symptoms.

Observational Data. The observational results are given in Table VII.

The main points shown are as follows: (a) complete control was obtained by using a 2% spray five times throughout the season, (b) one early spray at 2% on 28/3/45 delayed but did not prevent the onset of visual symptoms, whilst the later spray on 28/5/45 greatly arrested the late development of symptoms, (c) the 20 cwt. soil treatment only partially controlled the incidence of the deficiency.

Chemical Data. On 8/5/45 leaf samples were taken from the nil and 20 cwt. plots. On the later dates the sampling was extended to include the sprayed plants. The results are given in Table VIII.

TABLE VII.
PERCENTAGES OF MAGNESIUM DEFICIENT PLANTS AND SEVERITY MARKINGS.

Date	7/5/45		28/5/45		19/6/45	
MgSO ₄ Treatment	Block A	Block B	Block A	Block B	Block A	Block B
Nil	7 : slight	11 : slight	36 : med.- severe	37 : severe	70 : v. severe	68 : severe
20 cwt.	0.5 trace	2 : trace	21 : med.- severe	18 : med.- severe	47 : med.	34 : med.
2% spray applied 28/3/45 28/5/45	1 : trace	2 : trace	31 : med.	30 : med.	33 : med.	36 : med.
2% spray applied five times	Nil	Nil	Nil	Nil	Nil	Nil

TABLE VIII.
MAGNESIUM CONTENT OF TOMATO LEAVES.

Date	Mg Treatments	Nil		20 cwt.		2% spray (5X)		2% spray (2X)	
	Block	A	B	A	B	A	B	A	B
8/5/45	MgO as % Dry Matter	0.54	0.48	0.63	0.73	—		—	
20/6/45	„	0.27	0.24	0.35	0.41	1.60	2.08	—	
16/8/45	„	—		—		0.77	0.89	0.42	0.46

On 8/5/45 the treated Mg plants had a higher MgO value than the control. This is in agreement with the visual data. At the second sampling date the MgO level in nil plants was very low and the effects of treating with Mg is reflected in both soil and spray treatments. The greater increase in Mg content was effected by the spray treatment.

Although the MgO figures for the sprayed material may be too high, due to spray contamination on the leaf surfaces, the absence of visual symptoms suggests an adequate MgO content. It is interesting to compare the relative merits of the two spray treatments. Whilst the five sprayings produced complete control and maintained a high content of MgO in the leaves, in the two treatments which were only partly effective the MgO content was below the threshold value for deficiency when examined on 16/8/45.

Experiment 3.

The house was divided into two blocks, each containing five randomised treatments. The treatments, in duplicate, were as follows : (1) nil, (2) 10 cwt. MgSO₄ in base dressing, (3) 20 cwt. in base dressing, (4) 2% spray three times during the season, (5) 2% spray five times during the season.

The soil dressing was applied on 26/2/45. The grower's base dressing of N.P.K. was identical in all plots. The house was planted with Vetomold on 26/2/45.

The dates of spray application and details of the rate and the amount of magnesium sulphate used were identical with those reported for Experiment 2. In treatment (4) the third spray was applied on 7/5/45 and no more applications were given. The amount of MgSO_4 used for the three sprays was only $1\frac{1}{2}$ cwts. For the other spray treatment (5) a total of $3\frac{1}{4}$ cwts. was applied.

Slight foliage injury was recorded after the initial spray as for Experiment 2, probably due to the slow drying conditions in the absence of sunshine. No further spray injury was recorded.

Observational Date. The percentage plants showing visual symptoms, as well as the severity marking, are recorded in Table IX.

TABLE IX.

PERCENTAGES OF MAGNESIUM DEFICIENT PLANTS AND SEVERITY MARKINGS.

Date	7/5/45		28/5/45		19/6/45	
MgSO ₄ Treatments	Block A	Block B	Block A	Block B	Block A	Block B
Nil	1 : slight	3 : slight	6 : slight-med.	13 : slight-med.	35 : med.	36 : med.
10 cwt. ..	Nil	Nil	2 : trace	1 : trace	5 : slight	4 : slight
20 cwt. ..	Nil	Nil	1 : trace	1 : trace	4 : v. slight	2 : v. slight
2% spray (3X)	Nil	Nil	Nil	Nil	1 : trace	2 : trace
2% spray (5X)	Nil	Nil	Nil	Nil	Nil	Nil

Magnesium deficiency was not as severe in this house as in trials 1 or 2 at this centre. The soil applications produced almost complete control and the spray treatments were even more effective; the five applications being slightly better than the three.

Chemical Data. The chemical results for leaf samples taken on 7/5/45 and 19/6/45 are reported in Table X.

TABLE X.

MAGNESIUM CONTENT OF TOMATO LEAVES.

Date	Mg Treatments	Nil		10 cwt.		20 cwt.		2% foliage spray (3X)	2% foliage spray (5X)
	Block	A	B	A	B	A	B	A	B
7/5/45	MgO as % Dry Matter	0.51	0.45	0.61	0.65	0.81	0.70	—	—
19/6/45	„	0.30	0.23	0.40	0.46	0.49	0.57	0.70	0.76
								0.96	1.14

At the first sampling date the chemical data reflect the soil treatments. The magnesium content of the nil plants was near the deficiency level 0.50% MgO and visual signs were noted. On 19/6/45 the nil plants had the least magnesium content. The soil treatments, although recording higher MgO values, were near the threshold value for deficiency, and the visual symptoms corroborate the results. The leaves from treatment (4), sprayed 3 times, had

an adequate MgO content, and those from treatment (5) had a still higher level. In this instance the three early sprays (4) appear to have effected an economical and efficient remedy of the deficiency.

Centre III.

Two trials were conducted at this centre. The first was identical with a trial carried out at the centre in 1944, and was designed to compare the effects of various rates of magnesium sulphate applied as soil dressings with a 2% foliage spray. The second experiment incorporated 2% and 1% foliage spray treatments at various intervals during the season, and solution treatments applied to the soil around the plant roots.

Experiment 1.

The house was divided into 12 plots. The treatments were in duplicate as follows:—

- (1) Nil.
- (2) Magnesium sulphate at 5 cwt. per acre applied as a base dressing.
- (3) Magnesium sulphate at 10 cwt. per acre applied as a base dressing.
- (4) " " " 15 " " " " " "
- (5) " " " 20 " " " " " "
- (6) " " " 2% foliage spray five times during the growing season, making a total of $3\frac{1}{4}$ cwts. MgSO_4 per acre.

The base fertiliser dressing was given throughout the house and the magnesium sulphate in treatments 2 and 4 were applied to the soil on 13/3/45. The house was planted with Potentate on 15/3/45.

The spray technique adopted at the previous centre was used.

The 2% spray was applied on the following dates at approximately three weekly intervals throughout the growing season.

Date of spray application	Gall per acre	Lb. MgSO_4 per acre	Weather conditions	Spray damage recorded.
28/3/45	150	30	Dull	Trace on a few plants only
9/4/45	250	50	Sunny	No further damage
10/5/45	400	80	Sunny	"
28/5/45	500	100	Sunny	"
18/6/45	500	100	Sunny	"

Observational Data. In Table XI all plants showing visual signs of magnesium deficiency irrespective of severity are recorded. The number of plants affected are expressed as a percentage of the total number per plot and the severity marking for each plot is also given.

It is clear from Table XI that all treatments reduced the incidence of visual symptoms, but control at 5 cwt. rate was unsatisfactory. The 10, 15 and 20 cwt. rates all provided good commercial controls and no advantage was gained by increasing the amount above 10 cwt.

A complete control was obtained by the spraying technique where the amount used for the five sprays was under 4 cwt. per acre. The result again emphasises the superiority of the spray method over soil application.

TABLE XI.
PERCENTAGE OF MAGNESIUM DEFICIENT PLANTS AND SEVERITY MARKINGS.

Date	18/6/45		19/7/45	
Treatment	Block A	Block B	Block A	Block B
Nil	72 : severe	63 : medium	79 : severe	70 : med.-severe
5 cwt. per acre . .	35 : slight	48 : medium	43 : medium	54 : medium
10 „ „ „ . .	12 : v. slight	12 : v. slight	23 : slight	15 : slight
15 „ „ „ . .	8 : v. slight	9 : v. slight	20 : v. slight	16 : slight
20 „ „ „ . .	6 : v. slight	10 : slight	23 : v. slight	20 : slight
Foliage spray 2%	Nil	Nil	Nil	Nil

Chemical Data. Leaf samples were collected on 10/5/45 and 18/6/45. The chemical results are presented in Table XII.

TABLE XII.
MAGNESIUM CONTENT OF TOMATO LEAVES.

Date	Mg Treatments	Nil		5 cwt.		10 cwt.		15 cwt.		20 cwt.		2% foliage spray	
	Block	A	B	A	B	A	B	A	B	A	B	A	B
10/5/45	MgO as % Dry Matter	0.50	0.53	0.59	0.69	0.69	0.66	0.85	0.62	0.87	0.85	1.42	1.29
10/6/45	„	0.27	0.36	0.30	0.34	0.45	0.51	0.48	0.55	0.51	0.56	1.37	1.27

In soil treated plants the magnesium content of the leaves fell as the season progressed, whilst a high level, viz. over 1.0% MgO, was maintained in those from the spray plots. These latter values may again be too high due to residual spray deposits on the leaf, but the absence of visual symptoms confirm the adequate magnesium level.

The chemical results confirm the visual data in showing that (1) magnesium deficiency was very severe in the nil plots, (2) 5 cwt. treatment was inadequate to control the deficiency, (3) 10, 15, 20 cwt. were equally effective in arresting the onset of foliar symptoms, (4) 2% spray treatment was by far the best method of controlling the deficiency.

Experiment 2.

This house was divided into 3 blocks with six randomised treatments per block. The experimental treatments which were super-imposed on the routine N.P.K. base dressing were as follows :—

- (1) No magnesium sulphate.
- (2) 2% spray applied twice during the season.
- (3) 2% „ „ 3 times „ „ „
- (4) 2% „ „ 5 „ „ „ „
- (5) 1% „ „ 5 „ „ „ „
- (6) 2% spray of magnesium sulphate applied twice to the soil around the plant roots.

The house was planted with Potentate on 15/3/45.

The spray dates, the rates of application and mounts of magnesium sulphate used were as follows :—

Spray dates	Spray rate	Lb. $MgSO_4$ per acre	Gall. per acre	Weather conditions	Spray damage recorded
28/3/45	2% 1%	40 20	200	Dull	Trace tip burn in a few plants. More marked in 2% spray plots
9/4/45	2% 1%	50 25	250	Sunny	Nil
10/5/45	2% 1%	80 40	400	Sunny	Nil
28/5/45	2% 1%	100 50	500	Sunny	Nil
18/6/45	2% 1%	100 50	500	Sunny	Nil

Treatment 2 was applied on 9/4/45 and 10/5/45, and treatment 3 on the first three listed dates.

The amounts of magnesium sulphate used for the various spray treatments were approximately as follows :—2% five times, $3\frac{1}{2}$ cwt.; 2% three times, $1\frac{1}{2}$ cwt.; 2% twice, $1\frac{1}{3}$ cwt.; 1% five times, $1\frac{2}{3}$ cwt. The amounts emphasise the economical aspect of spray treatments as regards material.

The soil watering treatment was applied twice, on 28/3/45 and 10/5/45. The total amount used was $3\frac{1}{2}$ cwt., i.e. comparable to foliage spray treatment(4)

Observational Data. The numbers of plants showing magnesium deficiency symptoms were recorded on 25/5/45 and on 18/6/45. The results, expressed on a percentage basis, are given in Table XIII. The severity marking is also included.

TABLE XIII.
PERCENTAGES OF MAGNESIUM DEFICIENT PLANTS AND SEVERITY MARKINGS.

Date	25/5/45			18/6/45		
Plots and Mg Treatments	Block A	Block B	Block C	Block A	Block B	Block C
Nil	30 : med.-severe	25 : med.	18 : slight	63 : severe	57 : severe	54 : severe
2% spray 2 X	5 : trace	Nil	Nil	7 : slight	1 : v. slight	Nil
2% spray 3 X	Nil	Nil	Nil	Nil	1 : trace	1 : trace
2% spray 5 X	Nil	Nil	Nil	Nil	1 : trace	Nil
1% spray 5 X	Nil	Nil	Nil	Nil	1 : trace	3 : slight
2% watering to roots	28 : med.-severe	18 : med.	10 : slight	62 : med.-severe	32 : med.	51 : med.

All spray treatments were effective in controlling leaf symptoms, and treatment 2 (2 sprays only) was nearly as effective as treatments 4 and 5. Thus in this trial two sprayings, using as little as $1\frac{1}{3}$ cwt. of $MgSO_4$ per acre,

provided an effective control of the deficiency. At this centre a 1% spray with five sprayings, was also completely effective.

The liquid treatment to the soil, treatment 6, gave a poor control, although the amount used, viz. $3\frac{1}{2}$ cwt. per acre, was identical with that used in the heaviest foliage spray (*i.e.* treatment 4).

No chemical data were obtained at this centre.

Centre IV.

Two trials were carried out. The first was designed to test the relative merits of a 2% and 1% foliage spray applied at intervals during the season, and the second to compare the effect of soil and spray treatments as control measures.

Experiment 1.

The house was divided into eight plots and the following treatments, in duplicate, randomised in two blocks.

- (1) No magnesium sulphate.
- (2) 1% " " as a foliage spray 4 times during the season.
- (3) 2% " " " " " 3 " " " "
- (4) 2% " " " " " 4 " " " "

A base dressing of N.P.K. was applied to all plots. The variety Hundred-fold was planted on 25/3/45. Details of the spray treatments are as follows:—

Date applied	Spray rate	Lb. $MgSO_4$ per acre	Gall. per acre	Weather conditions	Spray damage
13/4/45	2% 1%	30 15	150	Sunny	Nil
10/5/45	2% 1%	60 15	300	Sunny	Nil
25/5/45	2% 1%	60 30	300	Sunny	Nil
19/6/45	2% 1%	100 50	500	Sunny	Nil

In treatment 3 the 2% spray was applied on the first three dates only.

Observational Data. The deficiency marking for each plot is given in Table XIV.

TABLE XIV.
PERCENTAGES OF MAGNESIUM DEFICIENT PLANTS AND SEVERITY MARKING.

Date	19/6/45	
Treatment	Block A	Block B
Nil	54 : medium-severe	48 : severe
1% foliage spray 4 X	4 : slight	6 : slight-medium
2% spray 3 X	3 : v. slight	5 : slight
2% spray 4 X	3 : slight	6 : slight

All the spray treatments considerably reduced the incidence of the deficiency. The data show no difference in the degree of control between the 2% or 1% sprays, and at 2% strength three spray applications were as effective as four.

Chemical Data. Chemical data on leaves taken on 19/6/45 are given in Table XV.

TABLE XV.
MAGNESIUM CONTENT OF TOMATO LEAVES.

Date	Mg Treatment	Nil		1% foliage spray 4 X		2% foliage spray 3 X		2% foliage spray 4 X	
	Block	A	B	A	B	A	B	A	B
19/6/45	MgO as % Dry Matter	0.26	0.31	0.56	0.63	0.74	0.92	1.14	1.03

The MgO content of the control plants was well below the threshold for deficiency and the severity of the visual symptoms corroborate the chemical result. All spray treatments substantially increased the magnesium level in the tissues and the data reflect the effectiveness of the spray treatments.

Experiment 2.

The house was divided into two blocks with 4 treatments in each. The grower's base dressing was applied and the following magnesium sulphate treatments given:—

- (1) 10 cwt. of magnesium sulphate as a base dressing to the soil.
- (2) 20 cwt. " " " " " " "
- (3) 1% foliage spray three times of 3 weeks during the season.
- (4) 2% " " " " " " " "

Treatments 1 and 2 were applied on 19/6/45. The house was planted with Hundredfold on 22/6/45. The total used in treatment 3 was 1 cwt. per acre and in treatment 4, 2 cwt. per acre.

Observational Data. No visual signs were recorded in the above plots, which may have been due partly to late planting or wholly to the effectiveness of the control measures.

Chemical Data. Leaf samples were taken from the plots on 16/8/45. The results are presented in Table XVI.

TABLE XVI.
MAGNESIUM CONTENT OF TOMATO LEAVES.

Date	Mg Treatments	10 cwt.		20 cwt.		1% foliage spray 3 X		2% foliage spray 3 X	
	Block	A	B	A	B	A	B	A	B
16/8/45	MgO as % Dry Matter	0.58	0.53	0.52	0.59	0.87	0.73	1.23	1.06

On this occasion the MgO contents of the foliage from treatments 1 and 2 were slightly above the critical deficiency value 0.50% MgO. The superiority of the spray treatment over soil application is evident from the results. The 2% spray appears to be superior to the 1% treatment, although magnesium deposit on the leaves may account to some extent for the difference.

DISCUSSION.

The aims of the 1945 experiments were (1) to confirm the 1944 results which had indicated that foliage spray treatments using magnesium sulphate were more effective than the use of this material as a base dressing to the soil, (2) to determine the most suitable rate of spray application to be effective without causing damage, and (3) to establish the minimum number of spray applications required to control the deficiency.

Trials at Centre I, Experiments 1 and 2, Centre II, Experiments 1, 2 and 3, Centre III, Experiment 1, Centre IV, Experiment 1 have all confirmed the 1944 result that a minimum of 10 cwt. per acre of magnesium sulphate as calcined kieserite (30% MgO) must be added to the soil to effect a commercial control of this deficiency. No appreciable advantage resulted from increasing the rate to 15 or 20 cwt. per acre. Evidence from Centre II, Experiment 1 suggests that soil treatment at 16 cwt. per acre produced little effect on the incidence of the deficiency the following season.

At Centre I, Experiment 2, Centre II, Experiment 2, Centre III, Experiment 1, the superiority of the 2% foliage spray treatment over soil application is shown both by visual effects and chemical analysis. For the foliage spray method as little as $3\frac{1}{2}$ cwt. of calcined kieserite was used for five spray applications and this provided complete control of the deficiency. Spray damage in the various experiments was negligible and only occurred under dull overcast weather conditions when the spray persisted for a longer time on the leaf surface. Injury was observed in a few plants only and was generally confined to the leaves with occasionally slight damage to the calyx, but fruit development was not affected. Damage never occurred in sunny weather, but further experience is necessary to establish the best conditions for spray applications.

The question of the minimum number of sprays necessary to control the deficiency throughout the growing period was examined at these centres.

At Centre II, Experiment 2, one initial 2% spray early in the season delayed the onset of visual signs but was not sufficient to give an economic control, whilst a 2% spray applied late in the season arrested the spread of the deficiency. Results obtained at Centre II, Experiment 3, Centre III, Experiment 2, Centre IV, Experiment 1 and 2 suggest that two or three applications of a 2% spray at intervals of three weeks during the early growing period provide an effective control of the deficiency. No advantage followed at these centres from increasing the spray applications to five.

At Centre III, Experiment 2, Centre IV, Experiment 1 a 2nd comparison was made between the efficiency of a 2% and 1% foliage sprays. It appears from the visual data that the treatments were equally effective and the chemical results also support this conclusion, although the actual MgO figures may be affected by the presence of spray material on the leaf surfaces.

Liquid spray treatment applied to the soil around the plant roots was much less effective than comparable foliage spray treatments, the results confirming those obtained in 1944.

The chemical data obtained in 1945 confirm the 1944 conclusion that the mid-season value of 0.50% MgO in leaves from the mid-stem portion of the plant can be regarded as a threshold value between sufficiency and deficiency of the element. It will be noted that spray treated plants usually recorded over 0.50%, whereas results from soil treated plants fell below this critical value. The result confirms the visual records that spray treated plants remained free from deficiency symptoms.

Recommendations.

The two main recommendations are as follows :—

(1) The 2% or 1% spray treatments are the most effective method of control. In all instances trial sprays should be applied to a few plants 48 hours before the main application. This precaution allows time for spray injury to develop. Both trial and main applications should be carried out under similar sunny weather conditions. A spreader such as sulphonated lorol at the rate of 10 oz. per 100 gall. must be included in the spray to prevent spray droplets remaining on the leaf surfaces.

(2) A commercial control can be obtained by incorporating 10 cwt. of magnesium sulphate (calcined kieserite 30% MgO) in the base dressing. This is not as effective as spray treatments.

Summary.

1. Further experiments were carried out at four centres on the control of magnesium deficiency in tomato.

2. A minimum of 10 cwt. per acre of magnesium sulphate was essential to effect a commercial control of the deficiency. No appreciable advantage resulted from increasing the rate to 15 or 20 cwt.

3. A soil application of 16 cwt. per acre produced little effect on the incidence of the deficiency the following season.

4. Foliage spray treatment at either 2% or 1% rate carried out four or five times at intervals of 3 weeks throughout the growing season gave a complete control.

5. Three 2% sprays applied during the early growth stage were as effective as five sprays.

6. One early spray was useful in delaying the onset of Mg deficiency symptoms and a subsequent late spray arrested their development.

7. The foliage spray treatments were superior to soil application both as regards effectiveness of control and economy of material.

8. Spraying should be carried out during sunny weather conditions as slight leaf injury was observed when sprays were applied on dull days.

9. The liquid application to the soil was relatively ineffective although amounts used were equivalent to those of 2% spray (5 X). This suggests that a soil factor is operative in inhibiting the intake of magnesium by the roots.

10. The chemical results agree with the visual data in reflecting the efficacy of the various treatments. The results confirm the 1944 conclusion that 0.50% MgO in leaves from the mid-stem position can be regarded as a rough index between a sufficiency and deficiency of the element.

Acknowledgments.

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REFERENCES.

- (1) JONES, J. O., NICHOLAS, D. J. D., and WALLACE, T. (1943). Experiments on the Control of Magnesium Deficiency in Glasshouse Tomatoes. Progress I. *Ann. Rept. Agric. and Hort. Research Station, Long Ashton, Bristol* (48-53).
- (2) JONES, J. O., NICHOLAS, D. J. D., and WALLACE, T. (1944). Experiments on the Control of Magnesium Deficiency in Glasshouse Tomatoes. Progress Report II. *Ibid* (61-71).
- (3) WALLACE, T. (1944). The Diagnosis of Mineral Deficiencies in Plants (with Supplement). A Colour Atlas and Guide. *London. H.M. Stationery Office.*
- (4) WALSH, T., and CLARKE, E. J. A Chlorosis of Tomatoes in Relation to Potassium and Magnesium Nutrition. *J. Roy. Hort. Soc.*, **70**, 202.

MANURIAL EXPERIMENTS ON VEGETABLE CROPS.

IX. EFFECTS OF FARMYARD MANURE AND OF VARIOUS FERTILISER TREATMENTS ON THREE VARIETIES OF POTATO.

By T. WALLACE and E. CATLOW.

The crops grown in 1945 comprised the seventh in the series of rotational vegetables grown on the plots since 1940 and followed garden beet grown in 1944 (1). The fertiliser treatments were as described for the preceding beet crops with the exception that nitrogen was applied as sulphate of ammonia at 3 cwt. per acre *vice* nitrochalk at the same weight per acre and superphosphate was given at 6 cwt. per acre *vice* 4 cwt. per acre for beets. The dung was spread over the ploughed land on 12/1/45 and the fertilisers were broadcast on 18/4/45, prior to working the soil for planting.

Three varieties of potatoes were grown—Majestic, Red King and Kerr's Pink—and planting was carried out on 24/4/45, with spacing intervals 2' 6" x 1' 6". Growth conditions throughout the season were good and regular spraying with copper prevented Blight infection. Harvesting was carried out after the tops had died down during the period 10/10/45 to 13/10/45. The weather was fine and the soil dry, and the crops were obtained in excellent condition.

RESULTS.

Leaf Symptoms and Vigour.

During the growing season the tops were scored for vigour and deficiency symptoms on four occasions between 12/6/45 and 29/7/45, during which period they passed through their most interesting growth stages. In making these visual records a point which showed up in striking fashion on each occasion was the differential behaviour of the varieties. Majestic was always least affected by unfavourable manurial treatments, as judged by foliage symptoms, and Red King most, whilst Kerr's Pink was notable for the striking leaf patterns produced by deficiencies, which mark it out as well suited for making deficiency studies. Red King, although severely affected by deficiencies, gave poor leaf patterns and for this reason is unsuited for indicating nutrient status.

The results of the visual examinations are summarised in the following Tables I, II and III. Where numerical values are given for vigour, the maximum possible score in each case is twelve, and is the total for three replicates.

June 12th. These records were obtained just prior to earthing up the plants. Colour differences due to manurial treatments were marked but no other deficiency symptoms had developed.

TABLE I.—VIGOUR MARKINGS 12/6/45.

Manurial Treatment	Dung	N.P.K.	N.P.	N.K.	P.K.	N.	N.P.KCl	N.P.NaCl
	10	12	10	6	6	6½	10	8½

It will be noted that the treatments omit P, omit N. and omit P.K., were much behind the others in vigour. The plants on these plots also showed outstanding colour effects, being dark bluish green for —P. and —P.K. and pale green for —N. The salt plots were also somewhat behind in vigour and the foliage was slightly pale.

June 16th. On this date the foliage colour was judged in the earthed-up plants, the results being as follows :—

TABLE II.—FOLIAGE COLOURS 16/6/45.

Manurial Treatment	Dung	N.P.K.	N.P.	N.K.	P.K.	N.	N.P.KCl	N.P.NaCl
	Slightly pale green	Medium green	Dark green	Dark green	Pale	Dark green	Slightly pale green	Pale green

Points of special interest are the pale colours on the plots receiving dung and fertilisers containing chlorides, and the paler colour on the NaCl plots as compared with the plots receiving KCl.

July 25th and 29th. Vigour markings were made by independent observers on these two dates and in addition very careful notes were made on growth characters, foliage colour and the incidence of leaf symptoms. The numerical data for vigour are shown in Table III, and the most important observations are summarised in note form.

TABLE III.—VIGOUR MARKINGS : 25/7/45, 29/7/45.

Manurial Treatment	Dung	N.P.K.	N.P.	N.K.	P.K.	N.	N.P.KCl	N.P.NaCl
25/7/45 ..	9	10—	7+	9	5½	7+	9+	8
29/7/45 ..	9½	9	8½	9	5½	7½	9	9½

The agreement between the two observers was close, with the exception of treatments N.P., N.P.NaCl, and to a less extent N.P.K. The data show clearly the comparable vigour for Dung, N.P.K., N.K., N.P.KCl, N.P.NaCl; and the less vigorous growth from treatments N.P., N., and P.K. It is thus clear that lack of vigour resulted from the omission of either nitrogen or potash; that omit phosphorus treatment did not result in decreased vigour at this stage of growth; and that chloride fertilisers did not reduce vigour.

A comparison of the results for treatments N.P., N.K., N. for June 12th and late July shows that whereas on the earlier date omit potash (N.P.) did not reduce vigour and omit phosphorus resulted in serious loss of vigour (N.K., N.), on the later date the position was reversed, and indeed during August the N.K. plots carried the best foliage of all the plots, whilst where potash was omitted, on N.P. and N. plots the foliage had completely collapsed and died down.

The chief points emerging from the qualitative data are as follows :—

- Dung* .. Leaf colour slightly pale green; magnesium deficiency leaf symptoms vary from trace to very slight.
- N.P.K.* .. Leaf colour medium green or slightly pale green; magnesium deficiency symptoms generally medium with some severe.

- N.P.* .. Leaf colour generally dark green; potassium deficiency symptoms medium with some severe; growth habit squat.
- N.K.* .. Leaf colour outstandingly dark green; magnesium deficiency leaf symptoms very slight and foliage freshest of all treatments; growth habit spindly.
- P.K.* .. Leaf colour very pale, yellowish green; magnesium deficiency symptoms generally severe with some medium (most severe of all treatments); growth habit stunted and few stems.
- N.* .. Leaf colour dark green; potassium deficiency symptoms variable but generally medium with some slight or very slight; growth habit mixture of squat and spindly types.
- N.P.KCl* .. Leaf colour slightly pale; few plants have magnesium deficiency leaf symptoms; younger leaves slight marginal scorch and spotting, and few shoot tips dying back.
- N.P.NaCl* .. Leaf colour slightly pale; no magnesium deficiency leaf symptoms; young leaves slight marginal scorch and spotting, and few shoot tips dying back as for KCl treatment.

Interesting points shown in these results are as follows:—

The leaf symptoms from dung treatment were those of low nitrogen status together with a trace of magnesium deficiency, the latter on plants near the edges of the plots and maybe the result of uneven spreading of the dressings. In contrast, the *N.P.K.* treatment, in which *K.* is given as sulphate, resulted in magnesium deficiency symptoms of medium severity and these later became severe. These plots showed in striking fashion that the continuation of this treatment over a number of years is likely to bring about an acute deficiency of magnesium, a point requiring attention where dung is not available for intensive cropping and reliance is wholly on fertilisers. A point of further interest in this connection is shown under the *P.K.* treatment, as here the omission of nitrogen intensifies the deficiency of magnesium beyond that shown by *N.P.K.*, an observation which has been confirmed in a number of other experiments with both vegetable and fruit crops. Where potash is not given—treatments *N.P.* and *N.*—potassium deficiency was serious and later led to the total collapse of the foliage. On the whole the effects were more severe for *N.P.* than *N.*, and it is of interest that in the latter case the plants in the early stage of growth suggested phosphorus deficiency rather than potassium deficiency, but later symptoms of the latter developed rapidly, although plants of the —*P.* type could even then be distinguished.

The plants receiving *N.K.* showed interesting features. From being very weak and spindly at the beginning of the season they gradually improved in relative condition, and towards the end of the season stood out as showing the freshest foliage of all the treatments and with the least leaf breakdown. Phosphorus deficiency leaf symptoms never developed, although the growth habit was typical, slight magnesium deficiency symptoms being the only type of leaf breakdown shown.

The plots receiving the two chloride treatments were notable for pale coloured foliage and for leaf symptoms totally different from the remainder of the plots. Magnesium deficiency never developed to more than a trace, in contrast to the *N.P.K₂SO₄* plots, and it may be that the chloride and sulphate ions affect magnesium nutrition differently, although the actual layout of the plots does not allow of an absolutely strict comparison of this point, as the chloride plots form a separate block adjoining the other treatments. The scorching and spotting of young leaves and the dying back of top shoots in

these treatments are attributed to chloride toxicity and in this connection it should be noted that the chloride treatments have been given annually to all crops since 1940 (both at 2 cwt. per acre) and that potatoes have been the only crop so far to show toxic effects.

The mineral status of the plants, under the various treatments, using Kerr's Pink, was compared by means of chemical tissue tests. The results are reported in another paper (p. 60), and it need only be stated here that these confirmed the observed differences in N., P., K., Mg. and Cl status shown by the foliage symptoms.

Crop Weights.

Yields were taken of total crops and ware and the results analysed statistically, excluding the chloride treatment plots which are not strictly comparable. In the Tables giving the results those for the chloride treatments are shown as a rough comparison. Varietal yields were also analysed and are included in the Tables.

TABLE IV.—TOTAL YIELDS. SHOWING MEAN YIELDS (TONS PER ACRE) AND ORDER OF YIELDS.

(a) *Manurial Effects.*

Manurial Treatments	Dung	N.P.K.	N.P.	N.K.	P.K.	N.	N.P.KCl	N.P.NaCl
Yields—tons	14.72	13.73	10.36	14.49	8.41	9.65	15.03	14.59
Order of Yields ..	1	3	4	2	6	5		

S.E. = 1.18; S.D. 5% = 3.71; 1% = 5.27

At 5% point: 1 and 2 > 4, 5, 6 and 3 > 5, 6. At 1% point: 1, 2, 3 > 6

(b) *Varietal Effects.*

Varieties	Red King	Kerr's Pink	Majestic
Yields—Tons	7.87	14.39	13.41
Order Yields	3	1	2

S.E. = 0.35; S.D. 5% = 1.01; S.D. 1% = 1.37. At 1% point: 1, 2 > 3.

For both total yields and ware there is a sharp separation of the treatments into two groups, Dung, N.P.K. and N.K. treatments giving high values, and N., N.P. and P.K. treatments low.

The results show that the two important factors in depressing yields are omission of nitrogen and potassium, the effects of which are similar in amount, though omission of nitrogen is somewhat the more serious of the two.

The yields of the two chloride treatments are similar to each other and to the three high yielding treatments in the main series, thus showing that the chloride toxicity effects noted in the haulms had not affected yields appreciably.

It should be noted that, in spite of the high yields for dung, the haulms suggested low nitrogen status, and it is possible that the yields could be raised appreciably by supplementing dung with a nitrogenous fertiliser. On the other hand, where nitrogen was probably adequate for high yields in the

TABLE V.—YIELDS OF WARE. SHOWING MEAN YIELDS (TONS PER ACRE) AND ORDER OF YIELDS.

(a) *Manurial Effects.*

Manurial Treatments	Dung	N.P.K.	N.P.	N.K.	P.K.	N.	N.P.KCl	N.P.NaCl
Yields—Tons	10.39	10.58	7.56	11.61	6.17	7.89	10.61	9.96
Order of Yields ..	3	2	5	1	6	4		
% Total Yields ..	70.60	77.11	73.02	80.09	73.35	81.79	70.60	68.22
Transposed Values ..	57.1	62.3	57.7	63.3	57.7	64.2		
Order %s ..	6	3	5	2	4	1		

Yields S.E. = 0.87; S.D. 5% = 2.74; S.D. 1% = 3.89

At 5% point: 1 > 4, 5, 6; 2, 3 > 5, 6. At 1% point: 1, 2, 3 > 6; 1 > 5, 6

% Total Yields S.E. = 1.22; S.D. 1% = 3.87. At 1% point: 1, 2, 3 > 4, 5, 6

(b) *Varietal Effects.*

Varieties	Red King	Kerr's Pink	Majestic
Yields—Tons	5.27	10.28	11.56
Order of Yields	3	2	1
% Total Yields	66.94	71.45	86.10
Transposed Values ..	54.7	58.3	68.1
Order of Percentages ..	3	2	1

Yields S.E. = 0.35; S.D. 5% = 1.02; S.D. 1% = 1.38

At 5% point: 1 > 2, 3; 2 > 3. At 1% point: 1, 2 > 3

% Total Yields S.E. = 0.27; S.D. 1% = 0.87. At 1% point: 1 > 2, 3; 2 > 3

N.P.K. treatments, the plants suffered severely from magnesium deficiency which emphasises the complexities of comparing the effects of dung and fertilisers.

The N.K. treatment, where phosphorus is omitted, is of interest, for here we have high yields from plots cropped continuously since 1924 without phosphate (strawberries 1934–1940, vegetables 1940–45) and where the plants in the early stages of growth were backward and showed evidence of low phosphorus status.

The low yields where potash is omitted, treatments N.P. and N. are of interest in that these treatments have given good yields of Brassica crops, which differ from the potato with regard to potash requirements. (See Table VI.) The low yield on the P.K. plots, where nitrogen is omitted, may be due in part to magnesium deficiency, which was more serious for this treatment than any other, a point which is shown by the data for the chemical tissue tests (p. 60).

Considerable differences were shown in the proportions of ware in total yields, and as will be seen in Table Va these were not in the orders of the actual

yields. There are again two well defined groups, the high percentages being shown in the two "omit phosphate" treatments, N. and N.K., and the N.P.K. treatment, whilst dung takes bottom place with "omit potash" (N.P.) next.

The data for varieties show that Majestic and Kerr's Pink gave similar results, whilst Red King, which appeared highly susceptible to all unfavourable conditions, gave yields of approximately 50% of the other varieties. Red King, in addition to giving the lowest total yields, also showed the lowest percentage ware. Whilst for total Kerr's Pink was slightly higher than Majestic, for both yield of ware and percentage ware the values for the latter variety were significantly higher.

Comparison with Yields of Previous Crops on Same Plot.

Since the present crop was the seventh in a continuous succession of vegetable crops on the plots it is of interest to compare the effects of the treatments on crops of widely different characters in the rotation. The relevant data are summarised in Table VI.

TABLE VI.—SHOWING TOTAL CROP YIELDS AS TONS PER ACRE AND ORDER OF YIELDS (VALUES IN BRACKETS).

Crop	Season	Manurial Treatments							
		Dung	N.P.K.	N.P.	N.K.	P.K.	N.	N.P. KCl	N.P. NaCl
Savoy	.. 1940	5.5* (5)	7.1 (2)	7.4 (1)	6.0 (4)	3.8 (6)	6.1 (3)	7.4	7.1
Carrot	.. 1941	34.6* (2)	34.6 (2)	30.9 (6)	35.6 (1)	32.6 (4)	32.2 (5)	34.4	38.4
Onion	.. 1942	3.7 (2)	3.04 (3)	2.17 (5)	4.35 (1)	1.66 (6)	2.45 (4)	5.50	5.25
Spring Cabbage†	.. 1942-43	5½ (5)	7½ (1)	7½ (1)	6 (4)	3 (6)	7 (3)	7½	7½
Cauliflower	.. 1943	8.3 (4)	9.6 (2)	10.3 (1)	7.2 (5)	3.9 (6)	8.5 (3)	13.9	13.9
Beet	.. 1944	10.18 (2)	10.75 (1)	6.79 (4)	7.77 (3)	5.72 (5)	3.92 (6)	13.26	15.53
Potato	.. 1945	14.72 (1)	13.73 (3)	10.36 (4)	14.49 (2)	8.41 (6)	9.65 (5)	15.03	14.59

* Dung at 5 tons per acre these crops; later crops at 10 tons per acre.

† The results for crop are for visual markings, as yields not obtained.

Whilst the yields for certain of the crops were not satisfactory, for reasons given in previous reports on this series of experiments, certain aspects of the manurial effects stand out very clearly as follows:—

Dung takes a high place for crops other than Brassicae, for which results are poor—doubtless due to a low nitrogen level.

N.P.K. treatment always ranks high.

Where potash is omitted, treatments N.P. and N., yields are high for Brassicae and low for other crops, thus showing the low requirement of the former for potash and its importance for carrot, onion, beet and potato.

Results for N.K. treatment show that phosphorus is important for the Brassica crops but much less so for the others.

Nitrogen omission—P.K. treatment—gives poor results for all crops and especially so for the Brassicae.

The two chloride treatments are associated with high yields for all crops, thus indicating that continuous treatment with chloride-containing fertilisers at the rate used (2 cwt. per acre) for a considerable period is unlikely to produce unfavourable results on a number of common vegetable crops.

Cooking Quality.

Cooking tests were made on random samples of ware potatoes from the plots, the tubers being boiled under a standardised procedure and judged by a panel of workers engaged in investigations of potato quality. The characters assessed comprised external appearance, flesh consistency, flavour and colour.

The results are reported in detail on p. 209, and it is only necessary to refer here to two points of interest relating to manurial effects, viz. :—

(a) The only manurial treatment which consistently affected colour was omission of potash, which produced slight blackening.

(b) The chloride treatments did not result in any appreciable lowering of quality, though salt treatment produced slight blackening of Majestic.

SUMMARY AND CONCLUSIONS.

1. Potato crops of the three varieties, Majestic, Kerr's Pink and Red King, were grown on plots used for continuous vegetable cropping and on which the effects of dung and various fertiliser treatments are compared. The crops were the seventh of the series.

2. Data were obtained relating to growth of haulm, foliage characters, mineral status of foliage, total crop yields and yields of ware and cooking qualities of the tubers.

3. The manurial treatments were reflected in the growth and foliage characters, and it was possible to distinguish, both visually and by chemical tests, effects due to low status of N, P, K and Mg and high contents of Cl. Dung resulted in low N. status, and treatments N.P.K. and P.K. were associated with Mg deficiency effects.

4. Deficiencies of nitrogen and potassium proved the most serious limiting factors to tuber production, whilst low phosphorus, although retarding growth at the beginning of the season, was later associated with good, healthy growth of haulm and high yields of tubers.

The tuber yields from dung treatment were similar to those for N.P.K., and it is probable that dung yields could be appreciably increased by a dressing of nitrogenous fertiliser.

Although chloride treatments caused injury to the foliage the yields for these treatments were similar to those for comparable N.P.K. treatments where sulphate is used *vice* chloride.

5. The potato varieties showed different reactions to the manurial treatments. Red King, in particular, was always most affected by unfavourable conditions, and the yield of tubers was only about 50% of those of the other two varieties.

6. The effects of the different manurial treatments on the yields of the seven crops grown on the plots since 1940 were compared. The data showed that low nitrogen and low phosphorus status were especially important in reducing yields of Brassica crops, whilst low potash status was not important for these crops but of great importance for the other crops—carrot, onion, beet and potato.

7. Cooking quality of the tubers was little affected by manurial treatment, though omission of potash resulted in slight "blackening" and salt also gave very slight blackening with Majestic.

REFERENCE.

- (1) PICKFORD, P. T. H. (1944). Manurial Experiments on Vegetable Crops. VII. *Ann. Report Agr. and Hort. Res. Stn., Long Ashton*, p. 71.

MANURIAL EXPERIMENTS ON VEGETABLE CROPS.

X. EFFECTS OF FARMYARD MANURE AND OTHER MANURIAL TREATMENTS ON GARDEN BEET.

By T. WALLACE and E. CATLOW.

The beet crop grown in 1945 was the seventh of a continuous series of vegetable crops which had occupied the plots. The preceding crop was cauliflower, variety November (Clucas), for which the results are given in the Annual Report for 1944 (1).

The manurial treatments for the beet crop were as for the cauliflowers, with the exception that the standard rate of nitrogen in the N.P.K. inorganic fertiliser treatment was nitro-chalk at 3 cwt. per acre *vice* at 8 cwt. per acre for cauliflower; the rate for vegetable compost was based on the dry matter equivalent of dung at 10 tons per acre, and a straw-sludge compost made at Long Ashton was used *vice* town refuse compost for treatment G at a rate based on the dry matter equivalent of dung at 20 tons per acre.

The bulky organic manures were applied on 11/1/45, previous to the spring ploughing, and the hoof and horn and inorganic fertilisers on 21/3/45 prior to the preparation of the seed bed.

Drilling of the seed was carried out on a good tilth on 14/5/45, four varieties being used on every plot in equal quantities (4 rows each), viz. Detroit Red, Obelisk, Covent Garden Red and Cheltenham Green Top.

Conditions on the plots throughout the season were favourable to growth. On all plots receiving the straw/sludge compost there was evidence of the presence of moles, but it was not possible to study this point in detail and the question must be left over for more exact observations in future crops.

Harvesting was carried out as follows:—Detroit, 6—8 September; Obelisk, 10—14 September; Covent Garden Red, 20—21 September; Cheltenham Green Top, 26—28 September. Although the weather was dull, harvesting conditions were good and lifting proceeded unhampered excepting for an unsettled period of showers towards the end.

Results.

During the growing season there were no obvious differences in growth characters of the foliage resulting from the different manurial treatments other than slight differences in vigour, and these were somewhat masked by a vigour difference between plots on the east and west halves of the area, a point which had been noted in a previous carrot crop on these plots. Vigour markings carried out on 25/7/45 gave the following results, as totals for three replicates, with a possible maximum of 15 points.

TABLE I.
VIGOUR MARKINGS 25/7/45.

Treatment	D*	B	F	A	C	E	H	G
	10 (1)	10— (2)	9½ (3)	9 (4)	9 (4)	9— (6)	8+ (7)	7+ (8)

* See Table II for key to index letters.

The treatments appear to fall into three groups for vigour: D, B, F; A, C, E; H, G.

The effects of the manurial treatments and of the varieties on yields are shown in Tables II and III.

TABLE II.
MANURIAL EFFECTS, ALL VARIETIES—YIELDS OF ROOTS IN TONS PER ACRE.

Complete N.P.K. with Hoof	Complete Inorganic N.P.K. with Potash Salts	Dung 10 tons plus ½ Nitro Chalk	Vegetable Compost equivalent 10 tons Dung + ½ Nitro Chalk	Dung 20 tons	Complete Inorganic N.P.K. with K ₂ SO ₄	Complete Inorganic N.P.K. + MgSO ₄	Straw/ Sludge Compost
D	F	B	C	A	E	H	G
20.12	19.23	18.98	18.90	18.45	17.32	16.04	15.18

S.E. = 0.80; S.D. at 1% point = 3.38, at 5% point = 2.43.

At 1% point D > G, H; B, C, D, F > G.

At 5% point A, B, C, D, F > G; B, C, D, F > H; D > E.

TABLE III
VARIETAL EFFECTS—YIELDS OF ROOTS IN TONS PER ACRE.

Detroit Red	Obelisk	Covent Garden Red	Cheltenham Green Top	S.E.	Significant difference	
					1% point	5% point
18.98	18.89	17.98	16.31	0.29	1.11	0.83

At 1% point Detroit Red, Obelisk, Covent Garden Red > Cheltenham Green Top.

At 5% point Detroit Red and Obelisk > Covent Garden Red.

The results in Table II show that Treatment D (Hoof, etc.) was outstanding for high yields and that Treatments H (inorganic fertiliser plus magnesium) and G (straw-sludge compost) gave significantly low yields. The yield of Treatment D was significantly higher than for E (N.P.K. inorganic) at the 5% level. In considering this last point it should be remembered that the rate of nitrogen in the hoof treatment is double that in the inorganic fertiliser.

From a comparison of the results for F and E it also seems that potash salts are likely to be superior to sulphate of potash for the beet crop, though the difference obtained fails to reach the point of significance.

In Table III it is shown that there were differences in yield between varieties, the main point being the low yield given by Cheltenham Green Top.

Summary.

1. Four varieties of garden beet were grown as the seventh crop in a continuous series of vegetable crops in which dung and other manurial treatments are under comparison.

2. The highest yields were obtained from a complete N.P.K. manure, using hoof and horn as the source of nitrogen, and the lowest yields resulted from straw-sewage sludge compost and from a complete fertiliser, containing N.P.K. plus magnesium sulphate.

3. Significant differences in yield due to varieties were obtained, the order from highest to lowest being Detroit Red, Obelisk, Covent Garden Red and Cheltenham Green Top.

REFERENCE.

- (1) PICKFORD, P. T. H. (1944). Manurial Experiments on Vegetable Crops. VIII. Effects of Farmyard Manure and other Manurial Treatments on Cauliflower. *Ann. Report Long Ashton Research Station*, 73.

CONCLUDING REPORT ON THE CROPPING OF 10-ROD WAR-TIME ALLOTMENTS AT LONG ASHTON AND IN THE CITY OF BRISTOL.

By E. W. HOBBS.

Introduction.

In February 1940 three demonstration 10-rod allotments, illustrating a 3-year rotation, were laid down at the Long Ashton Research Station, and three plots based on a similar plan were established at centres in the City of Bristol.

The Long Ashton Annual Reports for 1940 and 1941 included records of the initial cropping of these plots, from which certain practical conclusions were drawn.

These plots were maintained up to and including the 1944 season, so that detailed records are available over five full cropping seasons.

In Bristol, the three original plots were continued until the end of 1942, when the work in Bristol was delegated to a full-time Horticultural Officer appointed by the City.

The present account summarises the data for the Long Ashton plots for the five cropping seasons and for the Bristol plots for the period 1940-42 inclusive. Some observations are made on the three allotment areas in Bristol where demonstration plots were originally established.

Long Ashton Plots.

Cropping Plan. In the main the cropping plan followed closely that set out in Growmore Leaflet No. 1. Small modifications of the scheme comprised (i) the growing of 2 rows of parsnips in place of 3 after the second year, as the yield from 3 rows seemed more than the average household would consume; (ii) intercropping with early carrots, lettuce and beetroot which was found practicable to a much greater extent than was practised during the first year; and (iii) in the final year (1944) the omission of broad beans which were replaced by an extra row of runner beans sown late (June) in order to provide a tender, end of summer crop.

In order to avoid errors in following the cropping scheme and to secure accurate lining out and spacing of the various crops a detailed plan was drawn up at the beginning of each year showing the position of every crop and the necessary measurements for accurate marking out. The attached plan is an example of the one used in 1940.

Manuring. During the years 1940 and 1941 each plot received 20 lb. of sulphate of potash, 30 lb. superphosphate and 20 lb. sulphate of ammonia, the latter applied as top dressings to growing crops.

For the years 1942, 1943 and 1944 manuring was done with Growmore Fertilizer (7% nitrogen; 7% phosphate; 7% potash) at the rate of 56 lb. per plot, plus 25 lb. of sulphate of ammonia, 5 lb. of which was used on the compost heap each year and the remaining 20 lb. as top dressings.

At the end of the first season sufficient vegetable compost had been accumulated to dress lightly $\frac{1}{3}$ of each plot and although the amount of compost made annually has varied it has been possible to provide a dressing for $\frac{1}{3}$ of each plot each year. The weight of compost made on each plot each year has been between $3\frac{1}{2}$ and 4 cwt., providing a dressing equivalent to approximately $8\frac{1}{2}$ to 9 tons per acre, which compares favourably with the light dressings applied by the market gardener.

During the war emergency the compost and fertilizer dressings have been just sufficient to support a fair standard of cropping. There were signs, however, that the quality of crops was poorer and the yields smaller at the end of five seasons than in the earlier years. The drop in yield for 1944, however, cannot be attributed wholly to lack of fertility, as other factors, including adverse weather conditions in Spring and severe Root Fly attack on transplanted brassicas, contributed to lower yields.

No liming has been done throughout the period under review.

Pests and Diseases. The only major pest has been Cabbage Root Fly. Attacks in the early years were light, but they became progressively heavier in the following years, until in 1944 great difficulty was experienced in getting a full complement of brassica plants established without one liberal application of Calomel dust before and two after planting. Even under these conditions replanting became necessary on occasions.

Carrot Fly and Onion Fly have not caused any damage of note, and although Bean Aphis appeared regularly on broad and runner beans this was effectively controlled by timely spraying with nicotine.

Potato Eelworm, a scourge of so many established allotment areas was absent.

Crop Yields at Long Ashton. Detailed figures of the yields of each individual crops on each of the three plots have been kept over the five cropping seasons, and these data have been used to construct the summaries shown in Tables I and II. Table I shows the mean yield from the three plots for each year and the mean yield of the three plots over the five year period. Table II analyses the results into the mean yields per year of each individual vegetable.

Bristol Plots.

Sites. The three sites—Horfield, Chapel Lane and St. Anne's—were described in the earlier Reports.

Cropping Plan. The cropping plan followed closely on the lines of the Long Ashton plots, but most of the work on the plots was done by the individual allotment holders. A detailed field plan similar to that referred to in the Long Ashton account, was supplied each year to each allotment holder. Although

LONG ASHTON 10-ROD DEMONSTRATION ALLOTMENTS.

TABLE I.

SUMMARY OF TOTAL PLOT YIELDS IN LB.

Plot	1940	1941	1942	1943	1944	Totals	Means
1	1522	1874	1724	1735	1114	7969	1594
2	1674	2078	1848	1692	1145	8437	1687
3	1687	1980	1969	1770	1222	8628	1725
Totals	4883	5932	5541	5197	3481	25034	—
Means	1628	1977	1847	1732	1160	—	1669

TABLE II.

MEAN ANNUAL CROP YIELDS PER PLOT IN LB.

Beet	70	Potatoes	434	Leeks	70
Carrot	167	Sprouting broccoli ..	44	Spring onions ..	7
Parsnip	105	Sprouts	49	Bulb onions	103
Swede	46	Sprout tops	11	Shallots	16
Turnip	59	Kale	22	Total onions	196
Total roots	447	Spring cabbage	56		
Broad beans	13	Summer „	36	Marrows	64
Dwarf „	16	Autumn „	29	Lettuce	19
Runner „	49	Winter „	26	Spinach beet	29
Peas	29	Savoy	84	Tomatoes	16
Total legumes	107	Total Brassicae	357	Total miscellaneous ..	128

each of the Bristol plots was 10 rods in area, the outside measurements varied from one another and also from the dimensions of the plots at Long Ashton, but provision was made to secure approximately identical amounts of each vegetable on all plots.

Manuring. The amounts of fertilizers used on the Bristol plots during the first season (1940) were the same as those used at Long Ashton, viz. 20 lb. sulphate of potash, 30 lb. superphosphate and 20 lb. sulphate of ammonia. In the second season (1941) the St. George and St. Anne's plots received similar dressings. It was concluded after the first season's cropping at Horfield, however, that the fertilizer dressing needed increasing to raise the poor fertility level of the soil and the application of phosphates and potash was doubled.

In 1942 the fertilizer position had become acute and each plot received 42 lb. of Growmore Fertilizer in common with the Long Ashton plots.

The composting of every scrap of waste vegetable matter was made a feature on each plot. Some difficulty was experienced at Horfield and Chapel Lane in keeping the heaps moist enough in summer and the decomposition was not satisfactory until late autumn. At St. Anne's water was available, as was also a regular, although small quantity of lawn mowings, and the dressing applied to $\frac{1}{3}$ of the plot each year was rather heavier than found possible elsewhere. Owing to the sandy nature of the soil this was of special value.

Pests and Diseases. Attacks from insect pests in the second and third years in particular were much more severe from the beginning than on the Long Ashton plots, due possibly to the fact that the majority of plot holders round about made little or no effort to apply control measures. Cabbage Root Fly, Onion Fly, Carrot Fly and Bean Aphis caused damage in each area concerned, but routine control measures on the demonstration plots prevented any but the lightest damage.

Potato Eelworm appeared at St. Anne's, however, in the first season. The area had been allotment ground almost continuously since 1909, and the infection was general throughout the field.

Crop Yields in Bristol. Data are available for 3 seasons only, and the detailed records of crops of each vegetable on each plot over the three seasons have been summarised as for the Long Ashton plots.

Survey of Three Bristol Allotment Areas. In view of the fact that records on the Bristol plots were taken over a period of 3 years only, a brief survey of the three fields in which the demonstration allotments originally stood was made in the Autumn of 1945. Observations were made on a random selection of 9 plots and on the former demonstration plot in each area to determine what influence, if any, the system of cropping advocated during the war, and shown on the demonstration plot, had had on the methods and production of each allotment field.

Each plot was scored 3, 2 and 1 according to a satisfactory showing or otherwise under the headings, Planned Cropping; Winter Greens, sub-divided into pre and post Christmas crops; General Management. The results of this survey are given in Table V. It is of note that the mean score of 1.9 out of a possible 3 shows a balance well in favour of planned cropping (not necessarily the "Growmore" plan); the figures for winter greens show excellent provision for pre-Christmas green crops, with a fair but considerably less provision for greenstuffs for the New Year; the figure for general management leaves room for considerable improvement. Of the thirty plots visited only on twelve had any effort been made at composting garden waste and on very few had the composting been done in the proper manner. Burning of waste is still largely practised while many plot holders merely throw their garden rubbish into the pathways.

General Discussion.

The cropping of 10-rod demonstration allotments at Long Ashton presented no special difficulties. The land was in fair arable condition when taken over, with a medium available potash and phosphate content and the lime status was satisfactory. The ground was heavily infected with couch grass, but this was forked out during cultivations and never became a serious problem. The fact that the plots were under constant supervision enabled cropping to be maintained at a high level, and the plots produced fresh vegetables during every month of the year.

The Bristol plots were somewhat handicapped in comparison with the Long Ashton plots in that the three allotment holders concerned all lived at some distance from their plots and could only spend a small proportion of their time on them.

Soil conditions, too, and the initial state of the land were very different. The digging of the Horfield plot proved very laborious, but the turf was free enough from weed to be dug in and so improve soil texture. The plots at Chapel Lane and St. Anne's were both in a foul condition with perennial weed.

BRISTOL 10-ROD DEMONSTRATION ALLOTMENTS.

TABLE III.

SUMMARY OF TOTAL PLOT YIELDS IN LB.

Plot	1940	1941	1942	Totals	Means
Horfield	1115	1526	1317	3958	1319
Chapel Lane	1093	1184	1232	3509	1170
St. Anne's	1124	1212	758	3094	1031
Totals	3332	3922	3307	10561	—
Means	1111	1307	1102	—	1173

TABLE IV.

MEAN ANNUAL CROP YIELDS PER PLOT IN LB.

Beet	32	Potatoes	289	Leeks	61
Carrot	90	Sprouting broccoli ..	55	Spring onions ..	14
Parsnip	64	Sprouts	35	Bulb onions	80
Swede	16	Sprout tops	11	Shallots	7
Turnip	24	Kale	18	Total onions	162
Total roots	226				
Broad bean	21	Spring cabbage	56	Marrow	43
Dwarf „	14	Winter „	46	Lettuce	21
Runner „	34	Cauliflower	23	Spinach	12
Pea	34	Savoy	69	Tomato	14
Total legumes	103	Total Brassicae	313	Total miscellaneous ..	90

TABLE V.

REPORT AND ASSESSMENT ON THREE CENTRES (10 PLOTS PER CENTRE), 1945.

Scale of points: 3 = good; 2 = medium; 1 = poor.

Means for each centre.

Centre	General manage- ment	Planned cropping	Winter greens Before After Xmas Xmas		Total score	Remarks
Horfield	2	1.9	2.9	2.1	8.9	Greenstuffs, especially sprouts, fairly good. Increased yields where fertilizers applied.
Chapel Lane ..	2	2	3	2.2	9.2	Potatoes scabby; beans poor; greenstuffs starved except where fertilizers used.
St. Anne's ..	1.9	1.8	2.9	2.8	9.4	Severe eelworm infestation has reduced potato-growing. Club-root present in vegetables.

The Chapel Lane site was on a rubbish dump and the top soil when dug over consisted largely of coal ashes and other town refuse. The St. Anne's plot was easy to dig and cultivate, being light and sandy, and crops on the whole did well with the exception of potatoes, which were affected with Potato Eelworm from the first season.

In spite of these possible handicaps the three Bristol plots produced a mean yield of 1,173 lb. of vegetables over each of the three years, and excepting for potatoes, the plot holders concerned found this supply of vegetables sufficient for their own families.

Of the three Bristol plots the one at Horfield yielded better results than the two on the lighter allotment soils in spite of the extra labour involved in cultivating a soil of this type. Given reasonable amounts of fertilizer such soils produce good crops of greens, parsnips, onions, peas and beans. The high lime content allows of heavy cropping with greenstuffs without fear of Club Root. During the three years 1940, 1941, 1942, these demonstration plots served as examples of orderly planning and the manuring given provided visible demonstration of the value of fertilizers in areas where, generally speaking, manures of any kind were very rarely given.

The annual value of vegetables produced on a 10-rod plot has been computed at between £10—£15, valuing the crops at a low retail figure, but the high war-time prices would make the higher figure the more likely. The figure would not be reached where potatoes were grown in excess of the amount laid down in the "Growmore" plan. Potatoes are always comparatively cheap, and it is the all-important winter greens, and early crops of peas, beans and salads which are high priced in the shops. From the family budget standpoint, therefore, the cultivation of a 10-rod plot of ground can be a real asset.

Summary.

The cropping of 10-rod war-time demonstration allotments at Long Ashton Research Station and at three centres in the City of Bristol is discussed in detail.

The advantage of a planned and balanced scheme of cropping is shown to be essential on small areas of land if a twelve months' succession of vegetables is to be obtained and due prominence given to the growing of essential and high priced winter green vegetables.

Cropping results are given for Long Ashton and for Bristol and these show a mean yield of 1,669 lb. and 1,173 lb. from each plot over 5 years and 3 years respectively. The money value to the housewife of these crops is suggested as being around £15 per year.

Conclusions.

The data collected over five consecutive years of cropping of standard, 10-rod allotments at Long Ashton Research Station, together with three years' work on plots in the Bristol area lead to the following conclusions:—

(1) A ten-rod plot may yield from 1,100 to 1,900 lb. of miscellaneous vegetables each year.

(2) To produce a variety of vegetables in an orderly manner and to spread production over the year the cropping must be planned.

(3) The "Growmore" scheme has proved suitable for the planned cropping of allotments in the Bristol area.

(4) The amount of "Growmore" fertilizer (42 lb. per plot) allowed during the war was barely enough to maintain crop production and an increase would be necessary to maintain crop yields and soil fertility.

(5) Composting of vegetable refuse is shown to be advantageous, but few plot holders in the Bristol area made any attempt to use waste in this way. The composting of all vegetable waste from a 10-rod plot cropped on the lines of the "Growmore" scheme, shows that sufficient material can be accumulated in 12 months to dress lightly $\frac{1}{3}$ of the plot.

(6) The absence of any major disease on the demonstration plots (except Eelworm at St. Anne's) can be attributed at least in part to planned rotational cropping, as the incidence of Potato Eelworm and of Club Root has been noted elsewhere in Bristol where potato or brassica crops have been grown continuously on soils new to allotment cropping.

(7) The influence of the three demonstration allotments in Bristol on practice in the surrounding areas seems to have encouraged the principle of planned rotational cropping. The greatest change in cropping methods has been in the provision of fresh greenstuffs the year round, especially during Winter and Spring. This change, however, is not peculiar to the three allotment areas in question, but has been marked in allotment areas everywhere.

Acknowledgments.

The writer is indebted to Mr. J. E. Beviss for his voluntary help in the running of the plots in Bristol and at Long Ashton during the whole period under review.

REFERENCES.

- HOBBIS, E. W. A report on six 10-rod demonstration allotments in the Bristol district in 1940.
Long Ashton Res. Sta. Ann. Rept., 1940, 42—49.
 HOBBIS, E. W. Observations on the cropping of 10-rod war-time allotments—season 1941.
Long Ashton Res. Sta. Ann. Rept., 1941, 49—53.

HYDRAULIC SPRAYING MACHINERY FOR FRUIT CROPS.

THE CHOICE OF POWER EQUIPMENT.

By H. G. H. KEARNS.

INTRODUCTORY.

It is impossible to produce quality and quantity fruit crops at an economic price without a comprehensive spray programme. Each season £15—£30 per acre of apples should be expended on pest control measures. This high expenditure warrants considerable care in the choice of spraying equipment so that the maximum results can be obtained from expensive washes and labour at the minimum cost. Much of the equipment used in this country is inadequate for the tasks it is expected to perform. The purchaser and the manufacturer in many cases have not taken full account of the biological factors that must be observed for the successful application of washes. This has resulted in a wide range of machines of widely divergent design—many of them made individually to ill-defined requirements, a method of manufacture that is expensive and unsatisfactory.

A well planned underground mains system offers numerous advantages over all other methods of spraying. The initial capital expenditure is considerable, although over a period of years it proves no more expensive than other methods of spraying which are cheaper in first capital outlay but expensive to maintain and operate. During the 1939–45 war the “walk behind” mobile machine drawn and driven by a tractor has proved well suited for a wide range of orchards and it is likely to remain the most popular mobile type.

Further researches will reveal new disease and pest control materials and methods of application, but hydraulic pressure is likely to be the normal

method of application for some years. Recent reports of developments in the U.S.A. with large mobile outfits have attracted attention in this country. One type of machine is large and applies about 10,000 gallons of wash per day in the form of a "mist" spray created by injecting the spray fluid into a large volume of air of low pressure. The design aims at rapid application of washes on large acreages with a reduction of labour costs. It remains to be seen if these machines can be economically adapted to English conditions. It is clear that any development that reduces the cost of the most expensive item of fruit production must be explored. The present day lay-outs of many fruit plantations are ill-suited for efficient mechanisation, and it may be that future plantings may have to be made to suit the machine instead of the present method of making the machine fit the orchard.

The Biological Requirements of Spraying.

A fungicide or insecticide cannot be effective unless it is deposited in the correct place. Differences in the degree of control of diseases and pests obtained under experimental and commercial conditions are in many, if not most, cases explained by differences in the quality of the spraying. Under experimental conditions special care is made to secure the maximum coverage that is possible with the particular wash under test. For example, the eggs of aphides, sucker, winter moths, red spider and capsids cannot be killed unless they are covered by winter washes. The eggs are laid on upper, lower and side surfaces of shoots and the majority occur on bush and standard trees on the outer and upper twigs which are the most difficult to wet completely. It is therefore essential to arrange that the spraying of winter washes provides as nearly as possible a 100% wetting of the entire tree or bush. The control of woolly aphis and lichen by winter washes presents special problems in that the aphides are in cracks and crevices and only a prolonged drenching of the branches from all angles will achieve dislodgement and sufficient wetting to kill the aphides. Lichen is highly absorbent of moisture and the maximum control can only be obtained if it is dry and in an absorbent state when the wash is applied. The spraying at petal fall of apples is the most exacting of all applications as the control of apple sawfly depends on wetting the inside of the calyx cup and the control of red spider is only achieved if the lower surfaces of the leaves are completely wetted. Codling moth control requires an application at the end of June that completely covers twigs, leaves and fruitlets. The application of fungicides such as lime sulphur and copper-containing washes to fruit crops aims at protecting a growing leaf or fruit from spores. It is not necessary in the case of the leaves to wet both surfaces completely though each leaf must receive a reasonable coverage. This type of application is also satisfactory for the control of caterpillar by lead arsenate, as the larva almost invariably consumes a lethal dosage after nibbling a small portion of a leaf surface. It is fortunate that this type of application is suitable for the pre-blossom applications to apples and pears, as it eases the problems of spraying when time is often short.

If the above requirements are appreciated by the spray operator and acted on a marked increase in the quality of fruit would result.

Spraying Technique.

The above-mentioned biological requirements for spraying are not readily achieved under field conditions and every opportunity of assistance must be taken to achieve the results desired. Fortunately it is impossible to over-

wet a tree provided it is not allowed to dry, as the wood, foliage and fruitlets can only retain a certain amount of the liquid. The remainder "runs off" and generally speaking when "run off" occurs from all the surfaces there is no object in further spraying. However, it should be noted that "run off" will occur from some portions of the tree long before the entire tree is completely wetted. Some surfaces such as the lower surfaces of leaves, the stamens guarding the entry into a calyx cup and the "cots" round a plum fruitlet are difficult to wet. Therefore a surface active material (a wetter) must be added in sufficient concentration to the wash to achieve complete wetting. It should be noted that a wetter should not normally be added to a compounded oil emulsion.

A wash is equally effective if it is applied by a paint brush or by a high pressure spraying pump, but in the latter case the volume of liquid used may be at least nine times as great. The design of spraying equipment should aim at the application of the wash so that complete "coverage" is obtained with the minimum volume of expensive materials in the shortest period of time. If small volumes are used to reduce waste coverage can be achieved by using high hydraulic pressure or other source of energy. To date hydraulic pressure has been widely used and 400 to 500 lb. per sq. in. at the pump (say 200-400 lb. per sq. in. at the lance) has proved satisfactory: greater pressure does not materially improve performance and introduces various troublesome mechanical problems. The majority of the spraying is carried out by means of spraymen on foot directing a lance attached to a hose. Generally with present-day design of "brooms" considerable waste occurs if the delivery exceeds 7-8 gallons per minute. With automatic spraying the output must be sufficient to provide a "coverage" equal to that obtained with lance application: this requires a very large output, as the spray outfit is travelling past the trees or bushes and does not pause for individual attention. The output must be adjusted according to the road speed of the tractor. A relatively uniform surface of shallow depth such as a row of raspberries or loganberries is readily sprayed to ensure 100% coverage. The difficulties in obtaining complete coverage increase with the height and depth of a tree, a standard tree of 25 ft. and higher presenting considerable problems. Intercrossing branches, overlapping foliage and fruitlets obstruct the passage of droplets of wash and make it necessary to spray from two or more angles. It is impossible to obtain complete coverage by spraying from one side of a tree. The top and centre of a tall tree present the most difficult target and often the upper portions of branches are left unwetted although they appear covered from ground level.

The complete wetting of the under surface of leaves for the control of red spider presents the greatest difficulty. It can only be achieved by adjusting the angle of the spray so that it is applied under the leaves. This procedure slows up spraying considerably on low to medium height bush trees and increases materially the fatigue of the sprayman. The normal method of spraying only wets the upper surface of leaves and the greater the velocity of the wash the greater the difficulty of wetting becomes because the leaves become depressed and expose more of the upper surface. The small area of underleaf surface ultimately wetted in usual practice is largely due to splash from and contact with neighbouring leaves and low velocity drift.

It is desirable that visual fatigue shall be reduced as much as possible when the hand-operated lance is used. This is best achieved by a wide spray pattern as obtained from a multi-nozzle broom head, which is swept up and down the tree or bush. Unfortunately it is not possible to obtain width of

spray pattern and long carry without using a large delivery. Often the height of the tree, as in cherries, is so great that sufficient carry can only be achieved by using a single nozzle of 10 or more g.p.m. output, as the capacity of the pump is insufficient to supply a multi-nozzle broom. A single nozzle necessitates slow spraying to make sure of good coverage. The distance of planting of top fruit influences the quality of the spraying. A spray operator with a lance must have ample room to stand back from and walk round the tree he is spraying in order to obtain an adequate perspective. An overcrowded orchard is most difficult to spray and materially adds to visual fatigue. The optimum distance apart of trees and rows depends on the size of the tree, but in most cases a 15 ft. plant in an established orchard is insufficient both for the operator and the passage of mobile machines. The ease of spraying increases with an increase in planting distance. Hand operated lances are at their best with widely spaced trees, whereas the "automatic" spray machine is at its best in closely planted orchards of medium height trees, the limiting factor in the latter case being the risk of appreciable damage to outstretched branches especially when a large machine and tractor are used.

The Choice of a Spray Machine.

The choice of a spray machine in the past has often been decided by price and the recommendation of the manufacturer. The decision should be based on the extent of the spray programme of the orchard and the size of the equipment calculated so that it is adequate for the acreage. Practically every orchard in Great Britain is under-equipped with spraying equipment, and this is reflected in low quality fruit and often low yields. Quality fruit cannot be produced without an adequate spray programme. Faulty application reduces very considerably the value of all other cultural operations and wastes pest control materials. Often a pest such as capsid bug may be reduced in one season from devastating to negligible importance by adequate application of a winter wash, whereas spraying with inadequate equipment may take years to reach the same degree of control at an infinitely greater total cost of materials and loss of fruit.

Apples require a more comprehensive spray programme than any other crop. The size of the spraying equipment must be based on the volume of wash to be applied at petal fall. All varieties generally have to be sprayed within a period of ten days after petal fall. This time limit is often reduced by inclement weather and the large volumes of wash involved render it necessary to use adequate sized and reliable equipment. A breakdown at this stage may mean a financial loss considerably greater than the cost of a spray machine.

Young trees on a commercial orchard up to about 12-18 ft. high require not less than 500 gallons of wash per application, and bigger and older trees will require up to a 1,000 or more gallons per acre. The volume required for each spray stage will not vary greatly with the maximum for petal fall and the minimum at the green cluster stage. A mobile "walk behind" outfit is best operated with a tractor driver and two spray operators. If each sprayman handles an output of up to 7 to 8 g.p.m. a pump of 20 g.p.m. output is sufficient with a 250-300 gallon tank. This type of outfit fetching its own wash should apply, under average conditions, about 1,500-2,000 gallons of wash per day of six hours. Longer hours of spraying with the same team often lead to bad application due to visual fatigue. Therefore at petal fall the maximum acreage that can be sprayed within a period of 10 days, often

reduced to 7 or less by wet weather, is approximately 20-40 acres. At each of the "green cluster" and "pink bud" stages approximately the same acreage can be sprayed provided the weather is satisfactory. It should be noted that the most urgent need for efficient spraying against scab occurs in wet seasons at the pre-blossom stages. It would be wise to assess the capacity of the outfit as 30 acres for post-dormant spraying.

During winter a total of 50-100 acres can be sprayed when about 30-35 days are available which is equivalent to about 50,000 gallons of wash.

Smaller acreages can be sprayed by smaller outfits: an outfit with a delivery of 10 g.p.m. will be able to apply about 60-70 per cent., and the 3-5 g.p.m. small outfit about 20-40 per cent. of the volume of the 20 g.p.m. outfit. The small machine will not be suitable for trees higher than 12-15 ft.

If the mobile outfit is used for "automatic" spraying of top fruit and it travels at $2\frac{1}{2}$ m.p.h., it is necessary to have a delivery of wash of 35-40 g.p.m. to meet the varying orchard layouts and at the same time to take full advantages of this method of operation. These advantages are speed of application and avoidance of the hard labour of hand spraying. It should be noted that the quality of spray application by this method has not yet equalled that obtained by hand operated lances, nevertheless it is a method suitable for these washes that do not demand complete coverage. An outfit of this type fetching its own wash will apply approximately 6,000 gallons per day of 6 hours. A 20 g.p.m. mobile outfit may be used as an automatic sprayer provided the speed of the tractor is reduced to one m.p.h. and the trees are of medium size of about 12 ft. high. About 3,000 gallons of wash can be applied per day of 6 hours when the outfit fetches its own wash.

The alternatives to mobile spraying are the use of overland or underground mains. The overland mains are best avoided, as they involve the expenditure of considerable amount of labour in moving. The underground mains system with a pump house offers the best engineering layout over all other systems yet used in this country. It permits of almost continuous spraying, as the wash is immediately available from stand pipes, it permits of spraying when soil conditions render the use of heavy mobile outfits undesirable or even impossible. It avoids the wear and tear on a tractor and machine caused by hauling large weights of wash over the orchards, as each acre of apples requires 7-18 tons of wash in a season. The tractors used for hauling the mobile outfits are released for urgent work that is often postponed due to the urgency of spraying operations.

A spray operator in a working day of six hours will apply from stand pipes from 1,000-1,800 gallons of wash, the volume depending on the soil conditions and number of stand pipes of which 4-5 per acre are desirable. As a rough guide it may be calculated that about 50-75 per cent. of the total hourly delivery of the pump or pumps should be available for spraying, thus a pump rated at 20 g.p.m. should permit of the application in a 6 hour period of approximately 3,000-4,500 gallons, *i.e.* 6-9 acres at 500 gallons per acre.

In addition to selecting equipment of adequate volume output for the size of orchards, it is equally important in mobile outfits to select a size of machine that can be operated between the rows of trees or bushes without causing damage. Further details are given later on the section dealing with "Tanks." The tractor must also be suitable for orchard use, preferably a track-layer of low build with an underslung exhaust system. If a wheeled tractor is used it must also be of low build and fitted with wheel brake to facilitate easier turning at headlands. Generally, wheeled tractors of suitable dimensions for

most orchards are not suitable for mobile outfits of a laden weight of greater than 2-2½ tons. If the outfit is used for automatic spraying the power available must be sufficient for the dual duty of hauling the laden outfit and driving the pump. The pump requires about 1 B.H.P. for each 1½ gallon of fluid delivered at 400 lb. per sq. in. A laden spray machine of 2 tons laden will require at times 25 B.H.P. for traction.

A mobile spray machine and tractor suitable for operating between rows of top fruit trees or bushes is too wide for hauling between the rows of established currants, gooseberries or raspberries. This type of outfit is best operated with these crops from 12 foot alleyways spaced 150 ft. apart, the spray operators using short lanced brooms with hoses of 90 ft. length. If it is desired to spray the crops automatically it is necessary to use a narrow track tractor and spray machine. This type of tractor is generally of low horse power, and therefore it is necessary to use a self-engined spray pump with a small capacity tank. A suitable type of spray machine is a 100 gallon tank with a pump delivery of 10 g.p.m., this would permit at 2 m.p.h. of the application of approximately 300-400 gallons per acre. The overall width should not exceed 44 inches for a planting distance of not less than 8 ft. between the rows. A wider planting distance would be preferable for automatic spraying, especially late in the season when the bush is widespread. On land producing large bushes a planting distance of 10 ft. is essential.

CLASSIFICATION OF POWER SPRAYING EQUIPMENT.

The wide diversity of types of spray machines used by fruit growers has led to confusion in their description. For example the term "mobile sprayer" is used in different senses by different users, and it is desirable to adopt a terminology that is simple and accurate. The majority of the machines fall into the following classification of types:—

Scheme of Classification of Hydraulic Spraying Machines.

I. Stationary types.

- (a) Pump house. For underground mains systems.
- (b) Semi-stationary headland. For underground or overland main systems.

II. Mobile types.

- (a) Engine + pump + tank (manually, horse or tractor drawn). "Engined tank trailer" type.
- (b) Pump and tank drawn and driven by tractor. "Walk-behind power take off tank trailer" type (= trailer outfit).
- (c) Pump and tank drawn and driven by tractor. "Automatic type" (=trailer outfit semi-automatic, automatic).
- (d) Engine + pump + tank (self-propelled.) "self propelled" type.
- (e) Small engine and pump on wide variation of chassis ranging from "trolley" or "trailer chassis" with separate tanks.

I. Stationary Types.

The stationary and semi-stationary types of pumps and their ancillary equipment can be made with less regard for size and weight than mobile types. The fully stationary lay-out is installed within a permanent or semi-permanent building located to give the most efficient and economic delivery of washes to a inter-connected grid system of steel mains laid underground with suitably positioned stand-pipe take-off valves within the orchards. This system is the best for compact orchards which are not intersected by public roads, railways, etc. When the orchards are widely separated and of

relatively small acreage and have obstructed boundaries a central pump house cannot always be used, but the advantages of an underground system can be obtained by moving a semi-stationary type of outfit to a convenient headland with an adequate water supply. The washes are then pumped into the mains system *via* a suitable large-bore high-pressure flexible delivery pipe. This system can be conveniently described as the disconnected grid.

In some cases overland mains, despite their numerous disadvantages, are used to suit local conditions or methods of cultivation such as undercropping of apples with gooseberries. This system operates more or less in the same manner of underground mains with the difference that the overland mains are taken up and re-laid as the spraying progresses through the orchard. It is the labour of re-laying the mains and making sound connections between the lengths of pipe that makes this system cumbersome. In some orchards in order to reduce labour the overland mains are laid in convenient positions and the wash is carried out from them by means of very long hoses. This procedure results in arduous hose pulling and considerable loss of pressure unless small nozzle outputs are used.

The disconnected grid, underground and overland systems require a headland pumping outfit and so long as it can be moved from orchard to orchard its specification can vary considerably. A mobile type fitted with its own engine, pump and tank and readily drawn by tractor is the most convenient. So that spraying may proceed without interruption it is necessary to arrange that there is a continuous supply of diluted wash. This may be arranged by fitting a divided tank on the machine so that one tank supplies the diluted wash to the pump whilst the other is being filled. Alternatively and less conveniently a separate tank on the ground may be used. An adequate water supply must be available and it is best handled by means of a high capacity lift pump. The full advantage of a mains system are not gained unless the spacing of the pipes and the take-off valves (stand pipes) are arranged so that relatively short lengths of hose can be used. A hose length should be not more than 90 ft., as greater lengths slow up the work by arduous hose pulling. This requires the spacing of the mains and stand pipes at 108 ft., which is equivalent to $4\frac{1}{2}$ stand pipes per acre.

It is sometimes found that the inside walls of underground mains become "furred up" with consequent considerable loss of pressure. This is largely due to faulty lay-out which permits particulate matter to settle out, and may be reduced by arranging the pipe lay-out so that the velocity of the wash is maintained. A return circuit that connects up the ends of all lateral mains should be provided so that all the unrequired wash returns with adequate velocity to the pump house.

Extensive underground mains systems, especially on steep gradients, will require "booster" pumps to maintain pressure or alternatively the system must be divided up into sections with a separate pump to each section.

The essential equipment of a pump house consists of a pressure pump or pumps, electric or internal combustion motor or motors, mixing tanks and ancillary equipment. The details of the lay-out will vary, but they should aim at the efficient operation of the pumps and the minimum of manual handling of insecticides and fungicides.

II. Mobile Types.

The term mobile covers a wide range of spray machines that are mounted on wheels and capable of being moved by tractor, horse or manually. The

types range from small pump and engines mounted on small wheeled trolleys to large machines with 500 gallon tanks drawn and driven by tractors.

(a) *Engined tank trailer type.*

This type was very popular when the size of tank and delivery of the pump was small and therefore suitable for hauling by horse. The machines generally have four wheels with the front pair mounted on a turntable for easy turning. If the capacity of the tank is 200 gallons or more it is necessary to use a tractor for hauling it and it then becomes more economic to use the power of the tractor for driving the pump from a power-take-off. The only justification for using a separate engine to that of the tractor occurs when the outfit of 100 gallons capacity and tractor are both small, such as might be used for the "automatic" spraying of blackcurrants and similar closely planted soft fruits.

A large outfit with its own engine would be used for use with overland or in special cases of underground mains.

(b) *Walk-behind, power take-off, tank trailer type.*

This type consists of a trailer outfit of pump and tank mounted on two wheels or tracks and drawn and driven by the tractor. The drive for the pump is from the power take-off shaft. A smaller type would consist of a tank of not less than 250 gallons capacity with a pump of 10 gallons per minute output which is sufficient for one spray operator on medium to large trees or two operators on small bush trees or soft fruit. Normally the outfit would be operated by a tractor driver and a spray operator.

A larger type would have a tank capacity of not less than 300 gallons and preferably 400 gallons and a pump with an output of 20 gallons per minute. This type requires two spray operators and a tractor driver. It is more economic to operate than the smaller model.

The outfit is stopped in a convenient position between two rows of trees, and the spray operator or operators then walk round and spray a small number of trees. The length of hose is kept short and not more than 120 ft. When one group of trees has been sprayed the outfit moves on to the next convenient position, dragging the hoses. Under no circumstances should spraying be attempted while the machine is moving, as the quality of the spraying will be indifferent, especially on medium to large trees.

(c) *Automatic and semi-automatic trailer type.*

This type of outfit is of similar design but larger than (b), but the spraying is carried out with the machine moving slowly. If the spraying is from nozzles arranged on a tubular mast or grouped in a battery it may be conveniently referred to as "automatic." If the nozzles are guided by an operator it may be referred to as semi-automatic spraying.

This method of spraying requires either a very slow moving tractor (1 m.p.m.) or a pump delivery of not less than 35-40 gallons per minute at a tractor speed of 2-2½ m.p.h. to ensure a reasonable cover of the trees. The large capacity pump is preferable. The tank capacity should be of 400 gallons, and the tractor must develop sufficient power to drive the pump and haul the laden machine. This type of machine is under development.

(d) *Self-propelled type.*

Specially designed single purpose small machines of small delivery and tank capacity have been developed on the Continent and the U.S.A. for market

garden and estate work. Another type consists of the temporary attachment of small pumps to 2-wheeled garden tractors.

Most of these machines are compromises to meet demands for a machine that avoids the use of a horse or medium sized tractor. They are not suitable for anything more than a small orchard of about 1-3 acres comprising soft fruit or small bush trees.

Types with the output of the largest types of automatic outfit offer many attractions, but it is doubtful if the market would be large enough to warrant their development. They would be of particular interest to the spraying contractor.

(e) Small engine and pump on wheeled chassis.

Numerous models of small engine-driven pumps have been designed to meet the demand for an outfit of low initial cost. Many of them are too small for the efficient spraying of fruit trees. The minimum effective size of pump must have a delivery of 3-5 gallons per minute. The pump and engine may be mounted on a simple trolley chassis with small wheels which are only suitable for hauling on hard roads. Other models are mounted on light 2-wheel car trailer chassis with a single castor wheel in front so they can be hauled by a horse into position in the orchard. The wash is placed in tanks alongside the pump.

The outfits and tanks are moved to convenient points in the orchard, and to reduce the labour and loss of time caused by frequent moves very long lengths of hose are often used. This leads to undue loss of pressure and therefore efficiency that can be ill spared is lost from a small pump which is often used for work barely within its capacity.

Small pumps will enable good spraying to be carried out on small trees provided plenty of time is taken. This limits the use of the pumps to very small orchards.

BASES FOR SPECIFICATIONS.

The following broad specifications are described as a general guide for potential purchasers and manufacturers of spraying equipment required for fruit crops. They are not intended in any way to restrict or interfere with individual features of design, but there are some features such as pump capacities, general assembly of the machine and threads of hose couplings, etc., that require standardisation to the ultimate benefit of user and manufacturer.

Spray Machines.

Pressure pumps.

The high price of insecticidal and fungicidal washes makes it necessary to be reasonably economical with the volumes applied. It is therefore necessary that the sprayed fluid shall be broken up into relatively small droplets which cannot carry far unless projected by high pressure. The pressure at the lance during spraying should be not less than 200 lb. per sq. in., which often requires a pressure of 400 lb. per sq. in. at the pump. Considerable losses of pressure are often caused by using long hoses of a bore of insufficient size for the volume sprayed. These losses have to be met, as it is impracticable to use large bore delivery hoses. All pumps except the smallest sizes should be designed to operate up to 650 lb. per sq. in. and the small pumps at 300 lb. per sq. in.

It is desirable in the interests of economy of manufacture that the range of sizes of pump is limited. Pumps with outputs of 3 to 5, 10, 20 and 40

gallons per minute meet all present-day requirements. The efficiency of most pumps is lower than the calculated figure, as there are many factors under field conditions of usage that reduce the performance. The rated capacity of the pumps should be their output after they have pumped wash for not less than 80 hours at normal working speed and pressure.

It is desirable that the pumps, especially when fitted to mobile machines, shall be compact and of light weight, for example :—

3.5 g.p.m. delivery	..	1. — $1\frac{1}{2}$ cwt.
10 " "	..	2 — $2\frac{1}{2}$ "
20 " "	..	$3\frac{1}{2}$ — $4\frac{1}{2}$ "
40 " "	..	5 — 7 "

The pumps are normally of two types.

(a) *Ram plunger*, in which the packing is preferably self-adjusting and readily replaceable. Lubrication should be arranged within the packing assembly if the packing is composed of the normal square edge split ring type. If Chevron or overlap types are used the plunger on the non-pressure side should be constantly lubricated by oil. The plunger must be made of abrasion-resistant and non-corrodible steel.

(b) *Bucket assembly*, in which a single or double canvas reinforced rubber cup operates in a porcelain lined or non-corrodible abrasion-resistant steel cylinder. The bucket assembly must be readily replaceable. The lifting capacity of the pumps fitted with a single bucket is at times less than that of other designs, unless lubrication is arranged at the rear of the bucket to maintain an air-tight seal on the suction stroke. The loss of efficiency is perhaps compensated by the simplicity of the design. Double buckets, one for the delivery stroke and one for the suction stroke, overcome any loss of vacuum of the suction stroke, but it is essential to arrange adequate lubrication for the bucket to prevent rapid wear. If a double cap assembly is used it is essential to arrange for easy fitting into the cylinder. The buckets must be made of materials resistant to the action of tar and petroleum oil emulsions, lime sulphur and copper compounds.

The pump should be of a simple design consisting of the minimum number of component parts. External manifolds should be avoided as much as possible. All reciprocating parts should be totally enclosed, automatically lubricated, and the pump must be oil tight and fitted with a large filter plug and oil level cock or plug: easy draining must be provided. Large crossheads or their equivalent are essential to ensure the parallel movement of the plunger or buckets. If there is any likelihood of the crankcase oil becoming diluted with washes the ball and roller races and other bearings should be of non-corrodible steel. All bearings should be of generous proportions. The ball valve assemblies must be of adequate size, readily assembled, replaceable, and made of abrasion-resistant non-corrodible steel.

An air vessel or vessels should be provided of not less than double the calculated minimum capacity for the size of pump. The pressure control valve must not be a simple relief valve and it should be fully automatic and of sufficient size to ensure uniformity in pressure within the capacity of the pump. Preferably it should be fitted to the casting of the pump and be of the piston type.

Adequate and easy draining of the pump and pressure controller valve must be provided to prevent frost damage.

The speed of the crank or eccentric shaft of spray pumps varies between

50—250 r.p.m. The reduction in gearing from an electric motor or engine or power-take-off drive of a tractor is preferably arranged by means of totally enclosed sump lubricated gears. The gear box drive shaft must be mounted in large ball or roller races and the casing sufficiently substantial to withstand the loads imposed on it by a power-take-off shaft. In some cases a chain drive may be desirable, and it should be as short as possible between sprocket centres employing duplex or triplex chains totally enclosed in chain guards. If multiple vee belt drive is employed it must be totally enclosed. Adequate provision must be provided for the adjustment of the chain or belt drive and for lubrication of the chain.

Draining and storage of pumps and pipe circuits.

It is of the greatest importance that adequate provision is made for the easy and complete draining of the pump, pressure controller and pipe circuits. Imperfect draining may cause considerable delay or prevent the use of a machine the morning after a frost. With some designs of pumps, especially those with horizontal cylinders, it is difficult to drain them completely *via* the valves. If a small amount of water collects in the cylinder and it freezes there is a risk on starting a frozen pump of causing damage to the plunger and the cylinder head. Drain plugs are in many cases preferable to drain cocks, as the latter are easily blocked and may indirectly be the cause of frost damage. If drain cocks are fitted for ease of draining they should be frequently cleared with a probe (rimer). The drain cocks and plugs in the suction circuit should be a good fit, as any intake of air will reduce the suction efficiency of the pump.

Observations suggest that most of the depreciation of a pump occurs during storage. During the period between the completion of summer and the commencement of winter spraying considerable corrosion can occur in the crankcase, especially if ball and roller races are left above the oil level; corrosion of the valves and balls occurs and the packings become hard. Provision should be made for the easy and complete filling of the water passages and the crankcase with special rust resistant and water absorbent oil before the pump is stored.

Power-take-off drives.

It is preferable to arrange that the power-take-off telescopic shaft drive is in line with the centre of the chassis of the spray machine and arranged so that it is normally working with very little or no angularity. If tractors with offset power drives are used the pump drive shaft should be arranged to be in line with it.

The bearings of the knuckles of the telescopic drives should preferably be fitted with needle bearings, or if plain bearings are used they must be readily replaceable and adequate means of oil gun lubrication arranged.

The drive must be adequately guarded between the tractor and spray machine to remove all risk of injury to operators.

Tanks.

Tanks are required for the diluted washes. In stationary outfits a wide variation in size and shape is possible, as weight is not a limiting factor, but with mobile outfits the size, shape and weight must suit the lay-out of the orchards and the tractor.

(a) *Tanks for stationary outfits.* The lay-out of the pump house for economical operation should permit of a continuous supply of diluted wash.

The pump or pumps, tanks and accessory equipment should be arranged so that the need for the manual handling of liquids is reduced to the bare minimum. If the pipe circuits are well arranged it should be possible to avoid most of the dirt generally associated with the preparation of washes.

The essential requirements of a pump house apart from pumps and motor, etc., are a plentiful supply of clean water, a tank for pre-mixing some types of concentrates, two tanks for diluted wash and a measuring tank for the concentrates. There are various ways of arranging the tanks. They may be either above or below ground level; the former is generally more expensive as robust tanks and supports are necessary to carry heavy weights of fluid. Whenever soil conditions permit it is better to make concrete tanks *in situ* in the ground where they are more accessible and their position avoids all need for the lifting of heavy fluids. The only disadvantage is the small static suction lift imposed on the pressure pumps. This is of no consequence with most plunger pumps, but some types fitted with bucket plungers may require an overhead feeder tank for priming or permanently in the circuit to ensure their operation at optimum volumetric displacement efficiency. When it is necessary to provide a permanent overhead feed it is desirable to arrange that the feeder tank is supplied by a centrifugal pump with wash in excess of the plunger pumps capacity, the excess wash being returned to the main tank by an overflow pipe.

The supply of fresh water for diluting the concentrates may be obtained in some cases from a mains supply, but generally it is necessary to store sufficient water to supply a full day's spraying, the storage capacity necessary depending on the rate of replacement during the day and during non-spraying hours.

Three main tanks are required within the pump house, one for the efficient pre-mixing of winter wash concentrates, one for wash already diluted, and the third for wash undergoing dilution. The minimum capacity of the tanks is determined by the delivery volume of the plunger pump or pumps, which may be taken at not more than 75 per cent. of their hourly output. A convenient size for each of the dilution tanks is 300 or 600 gallons, *i.e.* working capacity of 250 and 500, which accommodates either 20 or 40 gallons (barrel) of a concentrate diluted to $7\frac{1}{2}$ per cent. approximately. Pre-mixing of the winter concentrates is a process which is generally omitted, and this often results in variations in pest control in different portions of the orchards, and also explains some cases of bud damage. A convenient capacity of a pre-mixing tank is 300 gallons (working capacity 240 gallons equivalent to 6 barrels). The agitation of the concentrate is readily and quickly carried out by either a manually operated paddle or by means of a plunger. It should be noted that the mixing of a wash in a full barrel by rolling or shaking is inadequate. In those cases where a whole barrel is used in one mixing the pre-mixing can be done in a dilution tank before the addition of the water.

The accurate measurement of small volumes of concentrates up to 25 gallons is conveniently carried out by fitting a measuring tank with delivery pipes over the dilution tanks. The concentrate such as lime sulphur is pumped by a large semi-rotary pump (No. 4 or 5) from the barrel into the measuring tank.

The agitation of the dilute wash may be either by power-driven paddles or more conveniently by means of a self-priming centrifugal pump with a displacement capacity of 40–50 gallons per minute. This arrangement avoids all the complications of mechanically driven agitators and permits of easy adjustment of the extent of the agitation.

The cement tanks must be prepared from a correctly made cement "mix" to prevent porosity and before they are put into use it is wise to dress them with one of the proprietary water proofing preparations.

(b) *Tanks for Mobile Outfits.* The tank of a mobile sprayer is the largest component of its construction and determines its width, height and length. It is therefore important that it is of a shape and size that offers the least possible obstruction to tree branches. It is also desirable but not essential that it should track with the tractor. In most present-day closely-planted orchards (15 or 18 ft.) in England the optimum width of the tank is 40 in. with an overall width of 65 in. (track 54 in.) and a height of 50 in. from ground level providing a ground clearance of not less than 10 in. The length of the tank is of little consequence, within reason, provided, in the case of the 2-wheeled "walk-behind" and automatic types, the balance is correctly calculated so that an adequate forward weight on the draw bar is arranged. The shape may be cylindrical, which offers the least obstruction to branches, of "U" shape with closed-in top which provides the maximum gallonage for a given height and width with satisfactory drainage and ease of manufacture of the machine.

The tank should be of all-welded design and be of iron of sufficiently heavy gauge to withstand distortion from rough usage and heavily galvanised after manufacture. If the machines are used with Bordeaux it is desirable to paint the inside of the tank when new and clean with two coats of a suitable bitumastic paint.

The tanks may be mounted on a chassis to which the axle or axles and pump are mounted, or the tank and chassis may be of composite all-welded design. In the former type $\frac{1}{8}$ in. plate is sufficient, but $\frac{3}{16}$ in. is generally desirable in the latter. With the composite design it is necessary to design the assembly to withstand torsion stresses caused by difficult soil conditions.

The filler hole of the tank should be round and of not less than 18 in. diameter and fitted with a deep filter basket and non-splash cover lid. The drain hole at the bottom of the tank should be not less than 2 in. B.S.P. size in a readily accessible position.

The design of the chassis depends on the type of machine. If the machine is of type (a), engine + pump + tank, the chassis is generally four-wheeled with the front axle mounted on smaller wheels and a turntable. This design if used for mobile spraying behind a tractor is wasteful of power as two engines are used instead of one, and the most economic use would be for semi-stationary headland work pumping into underground or overland mains. Generally, if the tank capacity is greater than 100 gallons, it is beyond the capacity of haulage by a single horse except under favourable conditions of soil and gradients.

The most easily operated and efficient types of outfits are (b) the "walk-behind" and (c) automatic. These are of two-wheel trailer type, with the chassis extended beyond the tank to form a platform for the pump, and having a draw bar attached to the underside.

The tank capacity should be not less than 250 gallons. The greater the capacity of the tank the greater the output of wash per day, as valuable time is not wasted in frequent fetching and filling up with wash. The limiting factor in the size of the tank is the ability of the tractor to haul it laden. Under good soil conditions tractors of the size of the Fordson and David Brown can haul a 300 gallon machine (laden weight 2 tons approx.), but under difficult conditions the load must be reduced to 200 gallons or less. Generally loads of 300 gallons and more are best hauled under winter conditions by

track-layer tractors. Tanks of 400 gallons and over require large tyres or tracks to avoid haulage difficulties on difficult soils.

A large tank is essential for the efficient operation of automatic mobile outfits, but for the "walk-behind" type it is more economic to limit the size to 300 gallons, as it permits of the use of medium size wheeled tractors.

The amount of spraying per day by either type is considerably increased by hauling wash to the machine by means of a tractor-drawn trailer tank.

The self-propelled types of spraying machine have only been made in small sizes of about 80–100 gallons capacity and the problems of tank design for large machines awaits development.

The separate tanks used with small outfits of type (e) range from 40-gallon drums with one end cut out to water carts. Generally a considerable waste of time and manual effort is expended in getting water to this type of outfit and moving it to new positions when used in orchards.

Axle equipment.

The machine should be mounted on rubber tyres, as this materially reduces wear and tear caused by steel wheels and permits of more rapid travel on hard roads. Two-wheeled tank machines should be over-tyred as determined by the normal formula for the axle loads, as low pressures are desirable to avoid undue bouncing on hard rough ground and to reduce sinking on soft land. Rubber tyres even on the largest machines are satisfactory. A machine with a 250–300 gallon tank (35–40 cwt. laden) requires 8 x 36, 8 x 19 or twin 6 x 32 tyres. A 400-gallon tank machine is best mounted on 9 x 24, 10 x 28 or 11.25 x 28 tyres.

Tracks may be used on very large machines, but they do not provide the soft travelling, simple maintenance and assembly of pneumatic wheels for grass orchards, and it is only on exceptionally difficult arable soil conditions that tracks are necessary, and it may be assumed that under such conditions the outfit should not be on the land.

The axle on two-wheeled outfits with a separate chassis is preferably square in section and securely attached to the chassis side members by "U" bolts. In outfits of tank-cum-chassis design a round axle is conveniently fitted through a transverse tubular tunnel welded to the side plates of the tank.

An outfit of 300 gallons capacity requires an axle of $2\frac{1}{4}$ in. diameter to ensure freedom from distortion.

The wheel hubs should be preferably mounted on taper roller bearings, but plain bearings are satisfactory provided adequate lubrication is provided for replaceable phosphor bronze bushes. At times the portion of the axle supporting the roller bearings is of too small a diameter, and this results in misalignment and rapid wear of the races.

The axle width should allow a tyre clearance under load of not less than 2 in. between cover and the side of the tank. A wheel inset into a cavity in the side of the tank to permit of an extra wide tank or to provide a "stream line" shape must have generous clearances between the tread and side wall of the cover, otherwise there is a risk under poor soil conditions of a wheel becoming clogged to such an extent that it is unable to rotate freely.

The provision of hub brakes is necessary under peace-time road traffic acts if the outfit is hauled on the public highway. Little advantage is gained from them under normal orchard conditions specially if the tractor is fitted with wheel brakes. If fitted the design of the hub and control mechanism must be superior to that normally fitted to agricultural vehicles.

Ancillary Components.

The ancillary components include agitators, tank filter baskets, pump suction line filter, foot and filter valves, riding platforms, water raisers (injector pumps), lift pumps, valves, suction and delivery hoses, hose couplings, spray lances, spray nozzles, spray guns, spray brooms, lance taps, spray bars and nozzle batteries.

Agitators.

Sufficient agitation is required to maintain a homogeneous mixture of the wash within the tank when it is full and as it empties.

Diluted stable emulsions such as tar oil and D.N.C. petroleums require very little if any agitation once they are mixed. Materials held in suspension such as lead arsenate, cuprous oxide, *Lonchocarpus* and D.D.T., require continuous agitation. This may be carried out by pump circulation with correctly positioned suction and delivery jets, by mechanically operated rising and falling perforated plate or by rotating paddles mounted on a shaft. The last-named method is the most simple and efficient provided the size, pitch, number and position is suitable for the dimensions of the tank. For example a tank of 300 gallons capacity 40 x 52 x 60 in., with a shaft positioned 12 in. from the bottom and fitted with two 2-bladed propellers 12 in. long x 3 in. wide set at 30° pitch rotating at 120–200 r.p.m., provides sufficient agitation for all normal purposes. The addition of a third propeller and an increase of the pitch of the blades to 45° and speed to 300 r.p.m., results in violent agitation which places heavy loads on the bearings.

The agitator shaft should be 1 in. diameter and mounted between two substantial phosphor bronze bearings in stuffing boxes and arranged so that the lubricant enters within the stuffing box packing and on the bearing surfaces.

The agitator drive may be either by chain or direct from the pump *via* a short shaft fitted with lubricated universal joints. The latter arrangement is preferable, but if a chain drive is used large duplex chain sprockets of $\frac{3}{8}$ in. size should be fitted and provision must be made for adjustment of the chain tension.

Between periods of use corrosion may occur between the shaft and stuffing box brushes and this may cause seizure. It is desirable to force grease into the bearing before storage and also to turn the pump over by hand before use to avoid drive failures.

Tank filter baskets.

It is important to use clean water for spraying as suspended matter reduces the efficiency of the pump and causes frequent stoppages due to blocked nozzles. Soft organic debris, such as portions of decomposing leaves, water weeds, etc., is particularly troublesome, as it rapidly fills the wire mesh of the filters. If organic matter restricts the flow of wash into the pump the delivery falls and the valves become noisy, and if the restricted flow is allowed to continue for long periods additional wear may occur.

Inorganic dirt is responsible for most of the wear of the valves and plungers. Large particles are readily trapped by the filters, but fine sand in suspension is most difficult if not impossible to remove unless mesh of impracticable aperture size is used. The fine sand becomes embedded in the plunger packings or the rubber insertion of bucket plungers and very rapidly abrasion of the plunger or barrel wall occurs. The wear on porcelain barrels is particularly

rapid once the hard surface glaze is destroyed. The presence of fine sand causes rapid enlargement of the small aperture of thin nozzle discs due to the high velocity of the outflowing liquid. In those districts where sand freely occurs in the water supply it is desirable if high maintenance charges are to be avoided to draw water from large tanks in which the sand has had time to settle out.

The main purpose of filters is to avoid stoppages of work due to blockages, and therefore they are essential for all types of hydraulic spraying equipment. The most convenient form for stationary and mobile outfits is a filter basket of circular design, made of a heavy gauge (14 G.) sheet with a flat bottom and galvanised after manufacture. In the side walls 3 in. diameter holes should be cut and covered on the inside with 24-mesh non-corrodible gauze, such as monel metal. The number of holes will depend on the size of the basket and volume of water flowing into it. A diameter of 20 in. and depth of 18 in. with fifteen 3 in. holes will be adequate for a flow of about 80 gallons per minute, and the in-flowing water should impinge on the flat bottom of the basket. Larger sizes may be used for stationary pumps, but they become heavy for easy handling.

When used on mobile outfits it is convenient to divide the basket into two halves by a partition, one half acting as a filter and the other left unperforated to act as a measure for the concentrate. The concentrate can be fed into the measure by a large semi-rotary pump and the measured volume discharged into the tank by means of a large "quick opening" plug hole. Generally it is unnecessary with factory-made concentrates to filter them, and should they contain any dirt it will be trapped by the pump suction line filter. If Bordeaux mixture is made in the tank the quicklime or hydrated lime would be added to the side of the basket for filtering the water and copper sulphate in solution pumped into the measuring side.

The water used with small outfits with loose tanks should be filtered through a basket before it enters clean tanks.

Suction line filters.

The provision of an efficient filter in the suction circuit of a high-pressure pump is desirable, as it prevents the accidental entry of any dirt, apart from fine sand, that has found its way into the wash tank. It should be of reasonably large size, as very fine soft organic matter can quickly block up a small area of fine mesh gauze. The filter for a pump of 10-20 g.p.m. delivery should consist of a steel or cast body with a quickly removable filter cage of about 8 in. long and 4 in. wide of 24 mesh non-corrodible material. Adequate provision must be made for drainage to prevent frost injury.

Suction foot filters and valves.

Suction filters on the end of hoses or pipes and placed direct into unfiltered water are best avoided on high-pressure pumps, as the vacuum causes rapid blocking up of the mesh and frequent cleaning is necessary with a wire brush. Some pumps, more especially those of the plunger bucket type, are slow in picking up fluid when started and a foot valve may be necessary to assist the low vacuum. The valve should be preferably of the phosphor bronze or stainless steel ball type on account of their reliability and self-cleaning action, and the effective port area of the valve must be as great or greater than the effective area of the suction pipe or hose.

Suction filters of large diameter are desirable on water raiser (injector)

or centrifugal pumps when dirty supplies of water are used. The filter must be designed to prevent any restriction in the flow of water, and it is preferable to avoid the use of any mesh gauze and aim at stopping the entry of small stones, etc. The filter should also be suitable for resting on the bottom of a muddy stream or pond. A suitable type consists of a "mushroom" shaped 18 G. steel pressing with the base without any apertures and $\frac{1}{4}$ in. diameter holes in the top. The total port area of the holes should be not less than four times the port area of the suction hose. The whole structure should be heavily galvanised after manufacture.

Water raiser pumps (injectors).

The rapid filling of the tanks with water is essential, and may be carried out by means of power-driven high efficiency self-priming centrifugal pumps or by a water raiser (injector) which has the advantage of being of simple design and trouble free. The water raiser is particularly well suited for mobile outfits, and if correctly designed it should lift at approximately four times the volume of the delivery of the jet feed operating at 200 or more lb. per sq. in. pressure with a suction lift of 7 ft. A delivery of not less than 35-40 gallons per minute is required for a tank of 300 gallons capacity. A smaller raiser with a delivery of 15-20 gallons per minute is suitable for small outfits. The higher the pressure of operation the greater the efficiency. The larger water raiser requires a hose of 2 in. bore and the smaller 1 in. bore. The feed jet of the raiser should be readily replaceable and the aperture made as large as possible, but within the maximum normal delivery of the pressure pump. An enlargement in size of the jet aperture or a drop in the delivery of the pump which causes an appreciable drop in pressure will reduce the efficiency of water raiser or even prevent it from operating.

Lift pumps.

Lift pumps range from manually operated semi-rotary to power-driven high efficiency self-priming centrifugal types. The semi-rotary types in the No. 4 and 5 sizes of 400-600 gallons displacement per hour are convenient for the transfer of concentrate in barrels to measuring devices in pump houses and on mobile outfits. They are too slow and arduous to work for pumping large volumes of water. The type with a cast iron body is suitable for all spray fluids if it is washed out with water after use and filled with oil before storage for some weeks.

Centrifugal pumps of the self-priming type capable of handling dirty water are well suited for the rapid handling of water concentrates and washes in a pump house. Types with $1\frac{1}{2}$ in. suction and delivery will deliver 45-50 gallons per minute, 2 in. type deliver 80 g.p.m. They give trouble-free service and require little maintenance. In pump houses they are conveniently driven by electric motor, but self-contained compact portable petrol engine driven models are available for other duties.

Valves (Cocks).

Various types of valves are used in the suction and delivery circuits of spray pumps. The most suitable type for suction is the gunmetal fullway, as this offers no resistance to the flow of the wash. It must be operated in the fully open or closed position to avoid wear of the faces of the wedge. A convenient size for pumps of 3-10 g.p.m. delivery is 1 in. B.S.P.; for pumps

of 10–25 g.p.m., $1\frac{1}{2}$ in. B.S.P. ; for 25–40 g.p.m., 2 in. B.S.P. (or two of $1\frac{1}{2}$ in. B.S.P. on separate suction circuits).

Delivery valves for hose unions and water raisers should be gunmetal steam valves with renewable discs of fibre or white metal. The sizes of $\frac{1}{2}$ in. B.S.P. cover all the requirements of delivery under pressure of 400 lb. per sq. in. up to 12 g.p.m. ; $\frac{3}{4}$ in. B.S.P. will be necessary for outputs up to 20 g.p.m.

The packing of the stuffing box of all valves should be impregnated with graphited oil to prevent wear and provide ease of operation and all threads coated with graphited paste packing to prevent complete seizure due to cementing by lime sulphur.

Hose couplings.

Hose couplings of numerous types are used particularly for high pressure hoses.

Suction hoses are best fitted with a lug nut and tail piece held in the hose by a Jubilee or similar simple adjustable clip ; wired-on couplings are an unnecessary complication. Hoses are preferably joined together either by lug nuts and a hexagonal parallel connector, but a lug nut and a male ended tail piece may be used. The couplings of delivery hoses are subject to pressures of up to 650 lb. per sq. in., and they are readily forced out unless special fittings are used. A common method of fitting is by means of tightly wrapped galvanised wire over the cover of the hose for the length of the tail piece : this method is not very satisfactory and requires special winding equipment to obtain sufficient tension.

Two or three piece clamps held on the hose over the tail piece by screws and nuts and fitted with retainer claws fitting into a collar on the tail piece are satisfactory and simple to fit. They tend to pick up debris when dragged over the ground, and they must be made of the correct radius to fit the hose expanded by the tail piece.

An excellent type of coupling consists of a collapsible steel cage which is squeezed into the cover of the hose and forces the lining on to a special short tail piece by a threaded collar nut. The coupling is of smooth external finish and does not pick up debris.

Hose couplings may be of three types, male-ended thread, nut-ended or hose menders. It is preferable to fit the ends of hoses attached to lances and valves with lug nuts for easy hand tightening. Hoses are conveniently temporarily joined together by means of hexagonal nut-ended hose couplings and a hexagonal parallel nipple. Male-ended couplings are best avoided for attachment of hoses to lances, as they do not permit of the ready adjustment of the lance to a comfortable working position. Hose menders are fittings for the repairs of a burst hose or for permanently joining lengths together.

The dimensions and threads of hose couplings are numerous and several of them unstandardised, the lack of standardisation being confusing to the user and the manufacturer. British Standard Pipe threads are used, but they are too fine for rough usage though they have the great advantage of being standardised. The thread is used for all British iron pipe fittings which are readily available in a wide range at low cost.

Various series of non-standard coarse threads have been developed by makers of spraying equipment which in most cases are not interchangeable. British standard Whitworth thread with specially wide standardised tolerances is suitable for all hose couplings and all bores of hose likely to be used on spraying machinery. The 1 in. Whitworth size is well suited for $\frac{3}{8}$ in. and

$\frac{1}{2}$ in. bore high-pressure hose, and it has been extensively tested under field conditions. It has a sufficiently coarse thread (8 t.p.i.) for quick and secure tightening by hand if a lug nut is used and it withstands rough usage. It avoids the disadvantages of the relatively fine thread of the British Standard Pipe size and the unnecessary large size and weight of the so-called 1 in. coarse thread (approximately $1\frac{1}{2}$ in. W.) now used.

The following Whitworth sizes increasing in increments of $\frac{1}{2}$ in. cover the normal requirement of spray hose couplings:—

$\frac{3}{8}$ and $\frac{1}{2}$ in. bore hose	..	1 in. W. (8 threads per in.)	
$\frac{3}{4}$ in. "	..	$1\frac{1}{2}$ "	6 "
1 in. "	..	2 "	4.5 "
$1\frac{1}{4}$ and $1\frac{1}{2}$ in. "	..	$2\frac{1}{2}$ "	4 "
2 in. "	..	3 "	3.5 "
$2\frac{1}{2}$ in. "	..	$3\frac{1}{2}$ "	3.25 "

Hoses.

Suction hoses are manufactured in light, medium and heavy duty types with embedded or exposed wire armouring in the bore. There is some confusion over their size description, and it is advisable to purchase them according to their bore after removal of any exposed internal armouring. The bore of specially prepared ends for the tail pieces of hose couplings should not be accepted as the true dimension. Hoses of 1, $1\frac{1}{4}$, $1\frac{1}{2}$, 2 and $2\frac{1}{2}$ in. bore meet all normal requirements. Variations in external dimensions is of little consequence, as simple adjustable hose clips can be used. They should be made of a grade of synthetic rubber mixture able to resist oil emulsions.

High-pressure hoses of $\frac{1}{2}$ in. bore were widely used before the war and, provided lengths of not greater than 180 ft. were used and the volume passed per minute at 400 lb. per pressure at the pump did not exceed 8 g.p.m., the loss of pressure was not excessive. During the war the use of synthetic rubber and inferior quality of cotton rendered it necessary to reduce the bore of the hose to $\frac{3}{8}$ in. and to retain the external dimension of the $\frac{1}{2}$ in. bore so that high pressures could be used without numerous bursts. The reduction in bore reduces the capacity of the hose, and lengths greater than 120 ft. cannot be used for volumes greater than 7 g.p.m. without considerable losses in pressure. It is preferable to use as short a length of hose as possible, as it reduces fatigue of the sprayman and loss of pressure. Not more than 120 ft. should be used and 60 to 90 ft. are the optimum lengths.

Except for exceptional purposes, hoses of greater than $\frac{1}{2}$ in. bore are not required.

Hoses made of wrapped canvas design are generally not so satisfactory as well-made braided hose, as they lack the pliability and easy flexure of the latter. Variations in the external diameter of delivery hoses results in difficulties in obtaining satisfactory fitting of the hose couplings. Hoses of $\frac{1}{2}$ and $\frac{3}{8}$ in. bore ($\frac{3}{8}$ in. war-time grade) with an external diameter of $15/16$ to $1\ 3/32$ in. are satisfactory for most couplings. When $\frac{3}{8}$ in. bore hose of high grade is available the full advantage of its light weight may be obtained by reducing the size to $13/16$ to $15/16$ in. The working pressure of the hoses should be 500 and the bursting pressure not less than 2,000 lb. per sq. in. The hose cover and lining must be made of a grade of rubber mixture that resists the action of tar and petroleum oil emulsions. The effective working life of a pre-war good quality braided hose was at least 3-5 years, provided it was stored when not in use in dark and damp conditions.

Nozzles, swirl plates and discs.

The variations in the performance of a nozzle for use with fluids under pressure is limited by simple factors and the multiplicity of designs is unnecessary. The relatively high price of washes makes it desirable to be economical with the volumes used, therefore the fluid is broken up into relatively small droplets, and this reduces their capacity to carry far unless high pressures are used. Variation in the "carry" is generally obtained by varying the size of the droplets. This is readily achieved by variations in the amount of interference of the straight flow exit of the fluid through the aperture. This interference is obtained by various simple mechanisms all depending on the same factors. A common design originated in the United States depends on interposing a plate (the swirl plate) with similar equi-distant holes drilled or slotted at the same angle and situated around the periphery.

The plate is placed beneath the disc aperture with the centres of the swirl plate and disc in line, the space between the aperture and plate being the swirl chamber.

A central hole drilled at right angles to the width of the swirl plate reduces the width of the spray pattern, increases the droplet size and thereby increases "carry." The ratio of the port area of the side holes and the central hole determines largely the character of the spray pattern. An increase in the size of the central hole results in increased carry of the spray pattern. Variations in the depth of the swirl chamber also influence the character of the spray pattern, but it is less confusing to standardise this to $\frac{1}{4}$ in. and obtain variations in the pattern by altering the type of swirl plate. A flat circular swirl plate of $31/32 \times \frac{1}{8}$ in. with the side holes of $5/32$ in. diameter drilled in the same plane and equi-distant at 45° in the arc of a radius of $9/32$ in. is commonly used with slight variations from these dimensions. A number of swirl plates with varying numbers of holes are available, but for all practical purposes a swirl plate with 6 side holes and one control hole of $7/32$ in. meets all the requirements for spraying bushes and trees up to a height of 15 ft. Greater heights require a swirl plate (long range) of 2 side holes and central hole of $5/16$ in. These swirl plates are fitted in nozzles with caps of $\frac{7}{8}$ and 1 in. B.S.P. thread or with brass thread (26 t.p.i.) to approximately these dimensions. A detachable disc of $1\frac{1}{8} \times 1/32$ in. is used.

The variation in the diameter of the nozzles operating at 400 lb. per sq. in. within $\frac{3}{4}$ to $1\frac{1}{4}$ in. B.S.P. sizes (1.04—1.65 in.) has very little influence on the spray pattern. The larger sizes are unnecessarily big and heavy, and nozzles of $\frac{3}{4}$ in. B.S.P. thread size are the most practicable size, as they are light yet convenient to unscrew by hand under field conditions. This size of nozzle is best fitted with swirl plates of $\frac{3}{4} \times \frac{1}{8}$ in. with slots cut at 45° equidistantly round the periphery instead of holes, as slotting is more readily carried out than drilling. The round central hole is drilled at right angles to the plate. By adjusting the size of the slots and central hole exactly the same performance of the larger swirl plate can be obtained. The replaceable disc should be $15/16$ in. diameter for a nozzle cap of $\frac{3}{4}$ in. B.S.P. size.

A slot of $5/32$ in. depth $3/32$ in. width at 45° and used with a nozzle gasket of $15/16 \times 9/16 \times 3/16$ in. is approximately equivalent in influencing the spray pattern as the round side hole of the $31/32$ in. swirl plate.

A nozzle used without a swirl plate has a long carry, but it is inferior both in carry and pattern to the swirl plate with a large central hole.

The aperture of the hole in the centre of the disc largely determines the delivery of this type of nozzle. The size of the hole is conveniently and

preferably quoted in 64ths of an inch. Sizes below 4-64ths are of little use for fruit spraying, 6-64ths is perhaps the most generally useful size, with 10 and 12-64ths for tall trees. The use of a disc of up to $\frac{1}{2}$ in. thick (a disc with a parallel central tube) increases the carry of the nozzle especially when used with a swirl plate with a large central hole.

The discs should be detachable and preferably $\frac{1}{16}$ in. thick and made of tough stainless steel to withstand abrasion.

Another simple nozzle design avoids the need for a central hole in the swirl plate, but requires a deep swirl chamber. Equal sized and opposite segments of a circular swirl plate are removed to act as portways for the flow of the fluid into the swirl chamber. An increase in the size of the portways increases the carry until the optimum is reached for the particular sized aperture of the disc. A swirl plate of $\frac{3}{4}$ in. diameter requires a swirl chamber depth of approximately $\frac{1}{2}$ in.

The two designs of nozzles can be modified and adjusted to give a wide range of similar spray patterns, ranging from a wide angle short carry "mist" of very small droplet size to one of very narrow long range of large droplet size.

The aperture of the disc controls the volume of fluid delivered by the nozzles provided the total area of the portways of the swirl plate is sufficiently large for the size of disc aperture. Each size of disc aperture at a given pressure requires a definite port area in the swirl plate to ensure the maximum delivery. This explains the big difference in delivery from a given size of disc when a spray gun is set to give fine and coarse spray patterns.

Spray brooms.

The nozzles are mounted on lances for convenience in handling. The nozzle may be single or mounted in series of two or more on a "broom" head set at right angles to the lance. This combination of broomhead and lance is popularly referred to as a broom.

The lance should be made of $\frac{1}{2}$ in. bore light steel tubing of 36 in. length, fitted with conveniently placed firmly fixed replaceable oil-resistant stout rubber hand grips. The top end of the lance should be bushed $\frac{1}{2}$ in. B.S.P.M. for attachment to the "broomhead" and the bottom $\frac{1}{2}$ in. B.S.P.F. for the control valve (tap).

The tap should be of a quick acting type, preferably a simple light lever movement for holding it in the "on" position. The wearing parts and the stuffing box must be of simple design and readily accessible, the valve parts preferably made of hard corrosion-resistant steel. The tap should be $\frac{1}{2}$ in. B.S.P.M. for attachment to the lance and tapped $\frac{1}{2}$ in. B.S.P.F. for fitting a connector $\frac{1}{2}$ in. B.S.P.M. x 1 in. W.M. for a hose lug nut.

The "broom" head is best made of aluminium reinforced by a brass tube or a tough aluminium alloy. It should be made as light as practicable. The number of nozzles may be 2, 3, 5 or more, but the number is governed by the delivery capacity of the hose and the passage ways in the broom and lance. The volume delivered to the broom must be equal to or greater than the total nozzle output otherwise the performance of the broom will be spoiled by starvation. As a rough guide the maximum capacity of 120 ft. of $\frac{1}{2}$ in. bore hose without greater loss than half the pump pressure at 400 lb. per sq. in. at the pump is approximately 9 gallons per minute, therefore not more than 4 nozzles with 6-64ths disc apertures and 7 hole swirl plates can be used. If $\frac{3}{8}$ in. bore hose is used 3 nozzles is the maximum number for 6-64ths discs.

Five nozzles can be used on 120 ft. if either $\frac{1}{2}$ or $\frac{3}{8}$ in. bore hoses of 4 or 5-64ths discs are used.

The distance apart of the nozzles affects the spray pattern, and the influence varies with the size of disc aperture and type of swirl plate. A convenient compromise to suit wide angle and long range spray patterns on the same broomhead is a spacing of $4\frac{1}{2}$ in. Spacings of less than $4\frac{1}{2}$ in. cause undue interference of medium angle patterns of neighbouring nozzles. A spacing of 9 in. apart provides excellent spraying of trees up to 15 ft. in height with 7 hole swirl plates, but for greater heights $4\frac{1}{2}$ in. spacing with long range swirl plates is best. A 5-nozzle broom with $4\frac{1}{2}$ in. spacing can be used dual purpose, by using 3 nozzles (the ends and middle) for shorter trees and the three middle nozzles for tall trees. Blank discs are fitted in the nozzles not required.

It is preferable that the nozzles should be detachable from the broomhead as this permits of cheaper repairs. The nozzle is best screwed into the broomhead by means of a $\frac{1}{4}$ in. B.S.P.M. close fit thread and the body of the nozzle standardised with a $\frac{5}{8}$ in. W. hexagonal to facilitate easy fitting.

The angle at which the nozzles are set on the broomhead to the lance is generally 15° . The best balanced broom is obtained with the nozzles in line with the lance and the balance is not upset by increased delivery. The greater the angle combined with the greater the nozzle delivery the more unbalanced and tiring to handle the broom becomes.

The nozzles set in line are suitable and preferable for all types of fruit spraying except for the control of Red Spider at petal fall. It is then necessary to wet the lower surfaces of the leaves on bush trees by means of nozzles set at 15° to $67\frac{1}{2}^\circ$: this is best obtained by fitting elbows between the broomhead and lance.

Spray guns.

If the single nozzle is mounted on a short lance and the portways of the swirl plate are instantly adjustable it is referred to as a "spray gun."

Spray guns with "quick set" swirl plates and not more than 30 in. length are very convenient to handle and permit of immediate adjustment of the spray pattern. They demand much more skilled operation than multi-nozzle brooms as they lack the width of spray pattern of the latter. The gun is sometimes preferred when used with disc apertures of 10-64ths or greater on tall trees, though the same spray pattern will be obtained from a fixed nozzle when fitted with the correct swirl plate and disc.

The gun should be fitted with a shut-off valve preferably as part of the swirl plate control rod.

Nozzle arrangements for automatic spraying.

When spraying is carried out automatically as a mobile machine passes trees or bushes, the nozzles can be arranged on varying lengths of steel tubing vertically at the rear of the machine. This arrangement may be described as a "spray bar" or "spray mast," and although it is the best way of obtaining the optimum performance from the nozzles, it presents difficulties in many orchards as the bar hits outstretched upper branches of the trees.

An alternative method is to group the nozzles together as a "battery" so they offer no obstruction to tree branches. This arrangement demands very careful adjustment and positioning of the nozzles. The nozzles should be readily adjustable for the angle of set and provided with quick acting

adjustment of the swirl plate. This method of spraying, unless exceptionally large outputs of wash are available, does not provide the quality of work of hand application.

Spray tank platforms.

Platforms on which the spray operator stands may be fitted on the top or rear of mobile outfits. If as previously described, the platforms are used for the operation of the normal multi-nozzle brooms, their use should be discouraged, as they result in poor spraying. The rear platform is desirable, as it provides the spray operators a safe method of travelling when not spraying. It should be provided with a 1 in. wooden platform 36 in. wide x 15 in. deep and provided with steel tubing side arms and a transverse holding rail fitted on the top of the tank. Preferably it should not be enclosed so that the men can jump off without danger of getting held up. The platform on the top of the tank must be substantially made to give the operator confidence of security when operating on rough ground. It should be either of a collapsible type or if permanently assembled readily removed. The floor must be of a design that provides the operator with a secure foothold.

SUMMARY.

1. Power-operated hydraulic spraying machinery for fruit crops is classified.
2. The biological requirements of spraying are described.
3. Guidance is given for the choice of spraying machinery.
4. Broad specifications for the principal components of hydraulic equipment are given.

EXPERIMENTAL SPRAYING PROGRAMMES ON APPLES AT LONG ASHTON: SEASON 1945.

By H. G. H. KEARNS, R. W. MARSH and H. MARTIN.

Introductory.

The discovery, during the 1939-45 war, of insecticides such as D.D.T. and benzene hexachloride, of much greater protective efficiency than those previously available, raises questions of their place in the fruit grower's spray programme. First, can advantage be taken of their greater persistence on the sprayed tree both to simplify the programme, and to extend it to deal with pests inadequately controlled by other insecticides? Secondly, if applied pre-blossom, will these persistent insecticides affect pollinating insects? Thirdly, as it is known that D.D.T., at least, does not control Red Spider, will the use of a summer acaricide compensate for the probable destruction of insects predatory on this pest? Normally the acaricide would be the lime sulphur washes applied for Scab control, but when petroleum oils are used as the acaricide a fungicide will be required which can be used in oil without causing spray damage. This last complication was accepted for the purpose of these trials, which consequently involved the testing of three fungicides, possible substitutes for lime sulphur, in combined washes based on petroleum oil added either as an acaricide or as a sticker. But the main purpose of the

experiment was to examine the effect on pest population of repeated applications of D.D.T.

In the current spraying programme for apples, control of aphid and partial control of spider is secured by winter washing. In the trials described below, winter washing, either with tar oil, petroleum oil or D.N.C., was omitted so that any pest control observed could be credited entirely to the spring and summer sprayings.

Plots.

The material available for spraying was a 3-acre plot, illustrated in Fig. 1. The eastern third of the plot comprised an almost solid block of Lane's Prince Albert: at the western end, Laxton's Superb occupied about one-fifth of the total area. Between these two varieties were mature trees of Worcester Pearmain in the alternate N—S rows, the intervening rows being of young Worcester or Superb trees. A few newly-raised seedling trees were scattered through the plot. All trees were 15 ft. apart on the square but the tree rows were shorter at the eastern end and in a circle 75 ft. in diameter near the S.W. corner all the trees were missing owing to enemy action.

The whole plot was in grass, and while the Superbs were vigorous and meeting in the rows, the Lanes and Worcesters were somewhat stunted, showing symptoms of nitrogen deficiency.

Materials.

The grade of D.D.T. used was stated to contain 81% of the *p-p'* isomer, and for the purpose of the trials was compounded to two forms:—

D.D.T.-Oil Stock Emulsion: As 100 gall. of the wash was required to contain 1 lb. D.D.T. and 1 gall. oil, a co-solvent was necessary, and a coumarone resin of low softening point, as suggested by the Geigy Co., was used. The resin ($\frac{1}{4}$ lb.) and D.D.T. (1 lb.) were dissolved in 1 gallon warm oil conforming to the M. of A. specification for petroleum oil summer washes for orchard use and the solution was emulsified when cold with $\frac{1}{2}$ gallon 7½% sulphite lye.

For application to a limited number of trees at the bud-burst stage, a similar preparation was used but with petroleum oil of the grade specified for winter use.

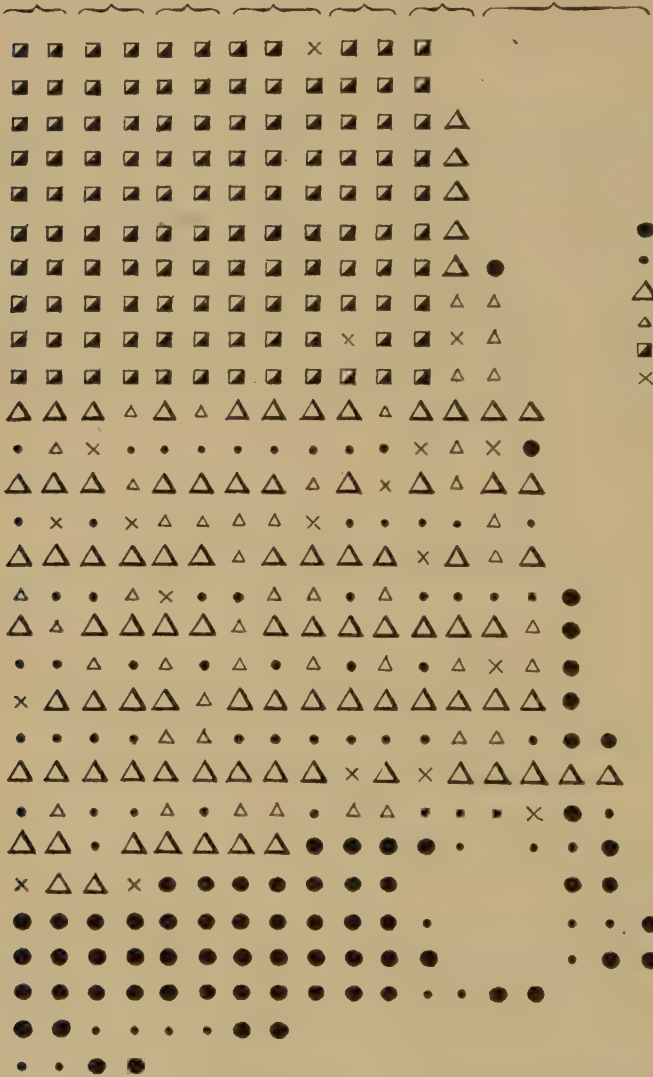
D.D.T. Suspensions. To obtain information on the suitability of various ways of compounding D.D.T. to products yielding a suspension on addition to water, two methods were employed. The first method used a solvent non-miscible with water but sufficiently volatile to ensure evaporation when the wash dried, thus leaving a deposit of solid D.D.T. on the foliage. The stock miscible oil was a solution in 2½ pints benzol of 1 lb. D.D.T. and 4 oz. anhydrous cyclohexylamine dodecyl sulphate, an emulsifier prepared at our request by Messrs. Ronsheim & Moore and now marketed under the name Product MB 320. This preparation was used for the early pink application on April 11.

The second method involved the use of a water-miscible solvent for the insecticide, and the stock solution used for dilution to spraying strength (0.1% D.D.T.) was prepared by the solution of 1 lb. D.D.T. in a mixture of 3.5 lb. acetone and 5 lb. Carbitol (di-ethylene glycol monoethyl ether) containing 0.5 lb. Sulphonated Lorol T.A. (50% aqueous solution of triethanolamine dodecyl sulphate). This preparation was used for the fruitlet application on May 19.

Ferric dimethyldithiocarbamate: The concentrate for 100 gall. wash was made with 2 lb. ferric dimethyldithiocarbamate, 0.2 gall. sulphite lye syrup

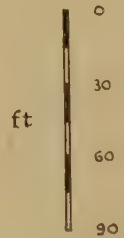
FUNGICIDE SPRAYS

T.M.T.D.S. Sebacate Lime T.M.T.D.S. Sebacate Fermate
 Fermate sulphur



KEY

- Superb
- do. (small tree)
- △ Worcester
- △ do. (small tree)
- Lane
- × other varieties



D.D.T. in oil
emulsion

No
D.D.T.

D.D.T. in
suspension

INSECTICIDE TREATMENTS

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
 Row No.

Fig. 1. Plot Lay-Out and Treatments.

and 1.8 gall. water. The lye was dissolved in the water, then the fungicide was stirred in and the whole ground in a ball mill for an hour.

Tetramethylthiuramdisulphide: This was prepared in the same way as the dithiocarbamate and used at the same concentration.

Copper Sebacate: Copper sebacate was used at 4 lb. per 100 gall. wash. The material was suspended in water after wetting with methylated spirit.

Lime sulphur: A commercial brand appearing in the list of officially approved products and therefore conforming to M. of A. specification.

Applications.

Lay-out of trial. The lay-out of the trial is shown in Fig. 1. Three east-to-west rows across the middle of the plot were the controls, sprayed at the green cluster, pink and two post-blossom stages with lime sulphur only. The remainder of the plot received D.D.T.; the washes used on the six rows north of the control strip all included petroleum oil: those used south of the control strip were without oil. The three experimental fungicides used—tetramethylthiuramdisulphide, ferric dimethyldithiocarbamate and copper sebacate—were repeated north and south of the control strip, *i.e.* they were applied both (a) with D.D.T. in oil emulsion (b) with D.D.T. in water suspension. Owing to the shape of the plot it was not possible to include one of the treatments on the Lanes: apart from this, Lanes, Worcesters and Superbs were included in all treatments.

Spraying programmes. The dates, stages and concentrations of the applications were as follows:—

Date	Stage	Rates per 100 gall.					
		L.S.	TMTDS	Fermate	Sebacate	D.D.T.	Oil
1. March 24 ..	Burst	—	—	—	—	1 lb.	1 gall.
2. April 11–13 ..	Early pink	3 gall.	2 lb.	2 lb.	4 lb.	1 lb.	1 gall.
3. May 18–19 ..	Fruitlet	1 gall.	2 lb.	2 lb.	4 lb.	1 lb.	1 gall.
4. June 26 ..	Midsummer	1 gall.	2 lb.	2 lb.	4 lb.	nil	1 gall.

(Spray 4 was not applied to the Lanes).

All spraying was carried out with a power sprayer and 3-nozzle brooms with 4/64 in. discs at a pressure of 400 lb. per sq. in. Heavy applications were given, averaging $2\frac{1}{2}$ to 3 gall. over both mature and young trees.

Weather. Late March and April were exceptionally warm and dry and the opening of the flower buds was approximately 3 weeks earlier than normal. On the night of April 30—May 1 a severe frost entirely destroyed the crop with the exception of fruitlets on the trees suffering from severe aphid attack. The remainder of the summer was generally cool and sunless but deficient in rainfall.

Biological Observations.

Pest infestation. At the beginning of March, approximately 15 % of the spurs bearing fruit were infested with one or two eggs of the Leaf Curling Aphis (*Yezabura malifoliae*): Red Spider (*Oligonychus ulmi*) eggs occurred on every spur but not in large numbers. Only an occasional egg of the Winter Moth (*Operophtera brumata*) could be found.

The majority of the aphid eggs hatched on March 20—22; Winter Moth commenced to hatch on the 22nd. Occasional feeding marks by the Apple Blossom Weevil were noted on the more advanced buds.

The first D.D.T.-petroleum wash on March 24, when the majority of the buds were in the early bud burst to early green cluster bud stage, although carefully applied, wetted only about 40% of the exposed area of the bud scales, but the shoots were completely wetted. The aphides within the cluster of flower buds were completely protected from the wash but some on the top of the clusters were wetted. The following day a few dead aphides were found on the sprayed and an occasional aphid on the unsprayed plots. At the pink bud stage on April 11 all the plots were sprayed and during the following two days moribund larvae of the Winter and Tortrix Moths were found. At this date it was evident that an aphid infestation was building up on the flower bud trusses.

At petal fall on April 30 frost temporarily checked leaf growth and the application of washes was postponed until the fruitlet stage on May 18. By May 22 an appreciable aphid infestation was evident on the lime sulphur control plot and some of the aphides were winged. During early June most of the aphides were leaving the trees. Syrphid fly larvae were present on all plots but on the D.D.T. plots the numbers were considerably fewer in number, possibly due to the meagre size of the aphid colonies.

The aphid attack on the control plot developed in a normal manner. The leaves curled and large colonies were produced which finally reached the winged stage. The only fruitlets which survived the frost were those of the aphid-infested trusses where the fruit was very small, distorted and pipless.

On the D.D.T. plots only very slight aphid distortion of the leaves of the flower trusses occurred and it was evident that an early attack, possibly by a few aphides, had been abruptly stopped and then the leaf had developed more or less normally. When an occasional colony became established and produced curled leaves, it either remained normal to the winged stage but more usually it died out.

The Red Spider infestation could not be interpreted due to the complications produced by spray damage which resulted in the partial to severe defoliation of some of the trees. It was observed that the foliage on the plots sprayed with D.D.T. petroleum oil at the fruitlet stage, especially the plot incorporating dithiocarbamate, showed considerably fewer symptoms of spider injury than the D.D.T. suspension (no oil) plots. The lime sulphur plot was appreciably infested, though less than the plot receiving the D.D.T. suspension, but this was to be expected, as the lime sulphur used without a spreader did not give a good cover of the lower surfaces of the leaves.

Scab infection. Scab was readily found by April 27 on Worcester and Superb. Throughout the season, the attack on Lane remained light. By rough estimation in July it appeared that the lime sulphur sprayed trees had less scab than those treated with other fungicides, but it must be pointed out that these trees were hindered by aphid attack from making the normal amount of scab-susceptible extension growth. Towards the end of the summer, scab became less conspicuous owing to dry weather conditions.

Results.

Methods of recording attack. (a) *Aphis infestation.* Aphis infestation counts were made on June 1, on Worcester and Superb, for each of the treatments: no insecticide, D.D.T. emulsion (3 applications), D.D.T. emulsion

(2 applications) and D.D.T. suspension. For each count, 4 or more trees were recorded and a total of at least 800 trusses was examined. Any truss showing the slightest sign of aphid attack was recorded as infected, irrespective of the fact that the degree of attack on individual clusters in the sprayed plots was usually much less than in the controls. Results of the counts are given in Table I.

TABLE I.
APHIS INFESTATION COUNTS. JUNE 1.

	SUPERB			WORCESTER		
	Trees examined	Flower trusses counted	% infestation	Trees examined	Flower trusses counted	% infestation
No insecticide	12	2385	29.2 ± 4.35	15	1705	51.2 ± 4.40
<i>D.D.T. Emulsion.</i> at bud burst, pink bud and fruitlet	7	1499	1.4 ± 0.48	9	1955	2.4 ± 0.35
at pink bud and fruitlet	4	935	3.6 ± 1.07	9	1552	4.3 ± 0.76
<i>D.D.T. Suspension.</i> at pink bud and fruitlet	7	1054	4.6 ± 1.52	6	802	8.4 ± 1.44

(b) *Scab*. Owing to the absence of crop, it was necessary to estimate scab attack from the leaves. The procedure adopted was as follows: the investigator stood in the alleyway between a pair of east-west rows that had had the same spray treatment and took his samples from the north side of the southern of the two rows (*i.e.* the side least liable to be affected by drift). For each tree sampled the main or sub-main branch system coming out at approximately eye-level nearest to the north was chosen and all leaves picked from this, thus giving a sample from a cone-shaped space extending from the outside to the inside of the head of the tree. From this sample 250 leaves were selected at random and each classified according to the percentage area scabbed. This grading was done by matching the leaves with the illustrations prepared for this purpose by Tehon & Stout (1930).

Leaves showing 0–2½% scabbed area were put in the category, No scab; those with 2½–7½% scab were classified as 5%; 7½–12½% were put in the 10% class, and so on.

An example of the data obtained and method of computing the sample value is as follows:—

(a) Percentage scabbed area per leaf	0	5	10	15
(b) Leaves per category	206	33	9	2
(c) Sum of products (a) x (b)	0 + 165 + 90 + 30 = 285			
Mean percentage scabbed area per leaf	$\frac{285}{250} \times 100 = 1.14$			

It is to be noted that a tree which gives a figure of 1% mean percentage scabbed area per leaf would be considered by casual observation to be moderately heavily infected. Results are given in Table II,

In view of the very low scab infestation figures on the Lanes, a statistical analysis of the results was carried out on the Superbs and Worcesters

TABLE II.
SUMMARY OF SCAB INFECTION RECORDS.
Mean percentage scabbed area per leaf, August 1945.

Treatment	Lime sulphur	TMTDS		Sebacate		Fermate	
		with oil	without oil	with oil	without oil	with oil	without oil*
Means	0.21	0.50	0.60	0.54	0.43	0.93	1.24
S.E.	0.0603	0.108	0.163	0.181	0.080	0.228	—

* No record on Lanes.

combined. This gave the following figures for mean percentage scabbed areas per leaf: Lime sulphur, 0.28; Sebacate, 0.63; TMTDS, 0.75; Fermate, 1.23. (For the three last-named, the results with oil and without oil were combined.)

Analysis of Variance.

	Degrees of freedom	Variance
Varieties	1	1.2613
Treatment	3	1.8493
Remainder	50	0.3022

Calculation of the significant differences between treatments showed that all other treatments were significantly better than Fermate: lime sulphur was not significantly better than Sebacate; and the difference (0.47) between the lime sulphur and the TMTDS means just failed to reach the level required (0.481) for significance ($P = 0.05$).

Spray Damage.

On April 16, slight to moderate lime sulphur scorch was noted on Worcester and Lane and slight oil damage on Lane. The dithiocarbamate-oil wash left a blotchy deposit much more obvious than that from the same fungicide in water suspension.

On May 24, a week after the fruitlet spray, leaf spotting due to oil damage was apparent, especially on the Lanes, and by June 18 the foliage of the oil-sprayed Lanes was almost entirely withered. The greatest damage was showed by the trees sprayed with oil plus sebacate. The oil applied in June did not result in further damage to the trees of Superb. In July, a purple spotting of the leaves of Superb was noted, particularly on the sebacate sprayed trees.

By September 10, the trees of Superb and Worcester sprayed with oil-sebacate showed marked defoliation: those sprayed with oil-dithiocarbamate had outstandingly green foliage. On all rows not sprayed with oil the effect of red spider infestation interfered with the assessment of spray damage.

Discussion.

The outstanding feature of the results is the high degree of control of the Leaf Curling Aphis obtained by D.D.T. Trees sprayed with washes containing D.D.T. showed 2-4% of flower trusses infested as compared with 51% on the control trees. It is doubtful if the applications at the fruitlet stage, when

the leaves on the control trees were already curled and the aphides becoming winged, could have made any appreciable contribution to the aphicidal effect. The control obtained must have resulted from the earlier applications and a comparison between the results of one pre-blossom and two pre-blossom sprays indicates that the second (applied at the pink stage) was sufficient to give control. The critical period appears to be after egg hatch, but before the development of leaf curling.

It must be emphasized that this result was obtained only on a single plot in a season of exceptional weather conditions. In view of the frequent records of failure of D.D.T. washes to control aphides, further trials under a wider range of conditions will be necessary to show whether a repetition of these results on apples can be generally expected. Meanwhile it should be emphasized that the use of D.D.T. at the pink bud and fruitlet stages was purely an experimental procedure and is unlikely to form part of a routine spraying programme.

Concerning Winter Moth and Tortrix control, the number of larvae observed was small, but on the sprayed plots all those found were moribund.

The Red Spider infestation developed as expected, *i.e.* it was worst on the plots sprayed with D.D.T. without oil and least on the oil-sprayed trees. The lime sulphur plot showed an intermediate degree of infestation which would probably have been lessened if the lime sulphur had been used with a spreader so as to improve the cover on the lower leaf surfaces.

The damage caused by the oil applications was serious, but there were contributory factors in frost damage and the poor vigour of many of the trees. It appeared that copper added to the oil enhanced the oil damage, but the addition of the dithiocarbamate or thiuramdisulphide did not increase oil damage and the former may have decreased it.

While no direct comparison was made between these last-named sprays and an oil-lime sulphur mixtures, the indications are that where summer oils are to be used with a fungicide, one of these organic sulphur compounds would be preferable to lime sulphur to minimise risk of spray damage. The scab control figures obtained in these trials, however, indicate that these compounds (at 2 lb. per 100 gall.) are inferior in fungicidal value to lime sulphur at the concentrations usually employed. Ferric dimethyldithiocarbamate has the further disadvantage that it leaves a tenacious and disfiguring deposit. The remaining fungicide used, 0.4% copper sebacate, provided a level of scab control which was not significantly inferior to that secured by lime sulphur, but the sebacate appears to exhibit, in some degree, the phytocidal properties common to all other copper fungicides.

SUMMARY.

Three acres of Worcester Pearmain, Lane's Prince Albert and Laxton's Superb apples, left unsprayed in the winter of 1944—45, were sprayed three times with D.D.T. between March 24 and May 19, 1945. Control trees were sprayed at the same times with lime sulphur only.

On half the trees receiving D.D.T. the insecticide was applied in an oil-emulsion wash; on the other half it was applied as a suspension. Comparisons of three fungicides—tetramethylthiuram disulphide, ferric dimethyldithiocarbamate and copper sebacate—were also included.

On the trees sprayed with lime sulphur only, a serious attack of leaf-curling aphid developed, 51% of the trusses being infested: on the D.D.T.-sprayed trees the infestation was only 2-4%. The trials indicated that the

D.D.T. applied at the pink stage had the most important effect in aphid control.

Red spider infestation was highest on the plots sprayed with D.D.T. without oil and lowest in the oil-sprayed plots. On the plot sprayed with lime sulphur (without spreader) infestation was moderate.

The application of oil at the fruitlet stage caused appreciable leaf damage to all varieties, especially Lane's Prince Albert. This phytocidal effect may have been enhanced by the low state of vigour of the sprayed trees.

The organic sulphur fungicides proved compatible with oil but less effective than lime sulphur in scab control. Copper sebacate was approximately equal to lime sulphur as a fungicide but may be damaging to copper sensitive varieties.

Acknowledgments.

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REFERENCES.

TEHON, L. R., and STOUT, G. L. (1930). Epidemic diseases of fruit trees in Illinois, 1922—28. *Ill. Nat. Hist. Survey Bull.* 18 (3), 415—502.

SOME OBSERVATIONS ON THE FLIGHT PERIOD OF THE CODLING MOTH (*LASPEYRESIA* [*CYDIA*] *POMONELLA*) IN WORCESTERSHIRE DURING 1944 AND 1945.

By S. H. BENNETT.

The satisfactory control of Codling Moth depends largely on the application of a cover wash or washes to kill freshly hatched larvae. It is therefore important to determine the optimum period of egg-laying. The moths are attracted to baited traps and in America this method is used to ascertain the flight periods of two or three broods. Fortunately, in Great Britain, there is generally only a single brood and the use of bait traps provides a satisfactory method of deciding the optimum period for spraying.

Trapping Technique.

Observations in 1944 were made by suspending at various heights in the trees, open topped metal trays 7 x 4 x 1 in. The trees were of the same variety randomised through an apple plantation in the West Midlands. This type of trap was not entirely satisfactory, as it permitted rapid evaporation or flooding by rain of the bait and removal of moths by birds. For the following season's observations, a lid was fitted with the space between the tray and lid of $\frac{3}{4}$ in. The trays were baited with 1 part by volume of beet molasses in 9 parts of water, the mixture being fermented with baker's yeast at the rate of $3\frac{1}{2}$ grams per litre (1). The bait in the traps was replaced every third day except in very hot weather, when bait was added more frequently to compensate for evaporation. The moths in nearly all cases were found floating on the bait, only a few being submerged.

The number of moths found in the traps can be regarded as giving an indication of the variations in population intensity over the period under review. Although no systematic data was collected on oviposition, it is safe to assume

that the peak of oviposition will coincide fairly closely with the peak of maximum activity of the moths.

Observations made on the ovaries of moths caught in the traps showed that there were rarely more than 6—10 fully developed eggs present. As the total number of eggs laid by a moth is far in excess of this, it suggests that individual moths may be egg-laying over a long period. The ovaries of moths caught late in the season are usually smaller than in those caught in late June and this again suggests that the moths trapped late in the season have been egg-laying for some time. The potential egg-laying capacity of late trapped moths is therefore less than those caught early in the season, and this point should be considered when studying the graphs.

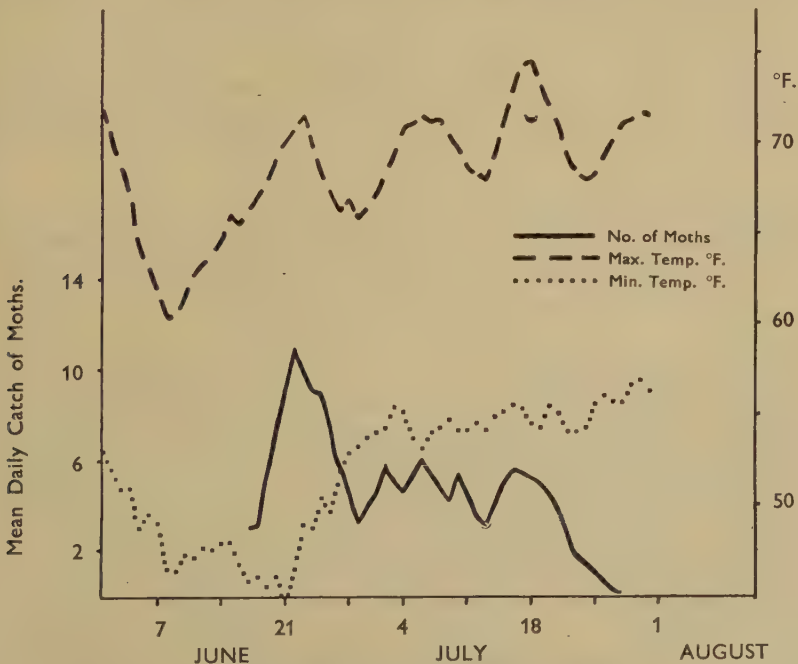
In a high proportion of the eggs found on fruit, the larvae on hatching do not enter the apple on which the egg was laid. It would appear to be normal for the newly-hatched larva to wander about the tree before selecting a fruit for entry. Often the larva enters a fruit for a short distance and then leaves it and selects an adjacent one.

The Flight Period of the Moths.

The flight period of the moths together with temperature records is presented in graphs. In the graphs the daily figure for total moths trapped and for temperature represents the weekly mean, *i.e.* it averages the figure for the day of recording, the three days before and the three days after.

Season 1944. Graph I.

Trapping commenced on June 10th and observations were discontinued at the end of July so that any second brood emergencies were missed. From the graph it is evident that the moths were on the wing in the orchard over a

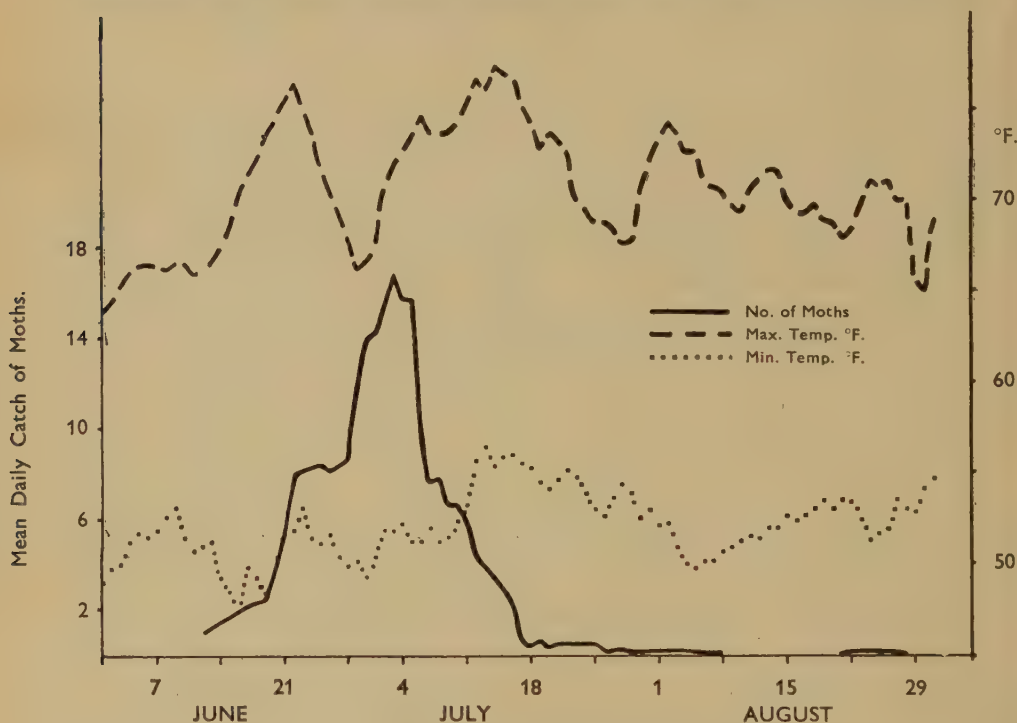


GRAPH I: SEASON 1944.

period of five weeks, reaching maximum numbers on June 22nd and then decreasing rapidly to the 29th. From that date emergence continued at an intermediate level until July 20th, and then fell progressively to the end of the month. We can assume, therefore, that the optimum oviposition period extended from the end of the third week of June to the end of the first week of July and continued from then with a gradual falling off to the end of the month. The incubative period of the eggs is normally 7—12 days, therefore the optimum egg-hatching occurred at the end of the last week of June and the first two weeks of July and continued at a lower level through the month.

Season 1945. Graph II.

Trapping commenced on June 10th and observations were continued to September 4th. The moths were on the wing in the orchard over a period of



GRAPH II: SEASON 1945.

seven weeks, but the main flight period occurred between the 19th June and the 15th July. There was a minor peak of activity on June 25th, with the main peak occurring on July 3rd, after which there was a rapid falling off to a lower level on July 7th and then a more gradual fall to a low level on July 18th. The period of maximum emergence of larvae was therefore over the first three weeks of July, a period almost identical with that of the previous year.

The flight periods of the two seasons differ slightly; in 1944, moth activity remained at a fairly high level with minor peaks during the first three weeks of July, whereas in 1945 there was a rapid falling off in activity after the peak period and activity was negligible after the end of the second week in July. This difference may possibly be due to differences in temperatures

between the two seasons. In 1945, of the 39 days between June 16th and July 24th maximum temperature were over 70° F. for the whole period with the exception of 6 days, whereas over the same period in 1944 maximum temperatures were over 70° F. on only 16 days. It is well known that the moths require warm still evenings for egg-laying and therefore the longer flight period in 1944 is probably explained by the lower daily temperatures.

Conclusions.

Although Codling Moth eggs may be laid from late May until August, it was evident from the data in 1944 and 1945 in a West Midlands orchard that the maximum hatching period occurred during the first two weeks of July. The degree of control obtained by arsenate sprays is likely to vary with the season. For instance, when the peak flight period of the moths is concentrated into a fortnight as in 1945, results from a single application of a cover wash will be better than in a season like 1944 when egg-laying was spread over a longer period.

When a stomach poison such as lead arsenate is applied at a stage of rapid fruit development, the cover soon breaks. It is therefore essential that the wash should be applied as near as possible to the time of maximum emergence of the larvae. In a season of short flight period the optimum results are generally obtained under West Country conditions by an application at the end of June. In a season of more prolonged flight, *i.e.* a cold early June, it may be necessary to apply a second wash two weeks later. If double spraying is carried out it is probable that the maximum control will be obtained by applying the first wash earlier, at the end of the third week in June and the second about a fortnight later.

Acknowledgements.

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REFERENCE.

- (1) BENNETT, S. H., KEARNS, H. G. H., and MARSH, R. W. (1944). *Ann. Rept., Long Ashton Research Sta.*, 1944, 157.

SOME FACTORS INFLUENCING LOSS OF ONION BULBS DURING STORAGE.

By H. E. CROXALL.

E. R. Wallace and C. J. Hickman conducted an investigation into the effects of time of lifting and method of storing on the loss of onion bulbs harvested in 1943 (1). They found that early lifting resulted in reduced losses. The experiments described in this paper were designed to determine if similar results would be obtained in the 1944 season. They also provided information on the susceptibility of different varieties to storage loss. The effects of different storage conditions and the influence of several fungicidal treatments were also investigated.

Experimental Methods.

The following six varieties, Bedfordshire Champion, Danver's Yellow Globe, Giant Zittau, Red Wethersfield, Rousham Park Hero, and Up-to-Date

were available on the same plot. Samples of bulbs were lifted on three occasions, Aug. 24th, Sept. 12th, Oct. 3rd. On the first date the onion tops of all varieties were just starting to die off but were still green. On Sept. 12th, the tops had almost completely died down and this date was just prior to the time the commercial crop on this plot was lifted. Between these two dates the tops of any onions not died down had been bent over. The tops of the variety Red Wethersfield had died down somewhat earlier than those of the other varieties. On the third time of lifting the tops of all varieties were withered and completely dead. On each occasion four replicates of fifty bulbs each were selected at random from each variety and placed in fruit trays. The soil adhering to the roots was removed as carefully as possible. Two replicates of each variety were removed to a greenhouse while the remaining two were kept in the open. The weights of each sample were recorded, but in contrast to the results obtained by Wallace and Hickman there was no statistically significant variation in the weights lifted on different occasions.

The effect of fungicidal treatment was investigated only with the variety Bedfordshire Champion, as there were not sufficient bulbs available of the other varieties. The treatments used were sulphur, a talc dust containing 50% tetramethylthiuramdisulphide, and a proprietary fungicide containing trichloronitrobenzene. Sulphur was used as several growers claimed that it reduced the losses brought about by rotting of bulbs. The proprietary substance is one successfully used for the control of *Botrytis* on lettuces while tetramethylthiuramdisulphide had shown promise in other experiments. Each fungicide was applied by a small hand-dusting machine. A good cover over the surface of the bulbs and leaves was obtained by using $\frac{1}{2}$ oz. of each dust to fifty bulbs. There were six replicates of each treatment and of untreated controls. Three replicates were placed in the greenhouse and three remained in the open.

In all experiments the trays were arranged in randomised blocks. The bulbs were examined on three occasions, Dec. 16th, Feb. 9th and April 24th. On each occasion bulbs showing any sign of decay or sprouting were removed and counts made of the remaining sound onions in each tray. The results were analysed statistically.

Experimental Results.

(1). *Varietal Susceptibility.* The percentage of sound onions of each variety remaining after each inspection is shown in Table I.

TABLE I.
PERCENTAGE OF SOUND ONIONS OF DIFFERENT VARIETIES.

Date of Examination	Bedfordshire Champion	Danver's Yellow Globe	Giant Zittau	Red Wethersfield	Rousham Park Hero	S.E.	Difference required for significance	
							5% pt.	1% pt.
16.12.44 ..	91	43.6	88.3	93.3	89.6	3.64	10.62	14.38
9.2.45 ..	62.6	18.3	66.3	72.6	66.0	6.64	18.58	25.14
24.2.45 ..	21	1.3	22.0	8.0	21.0	5.06	14.74	19.96

The variety Danver's Yellow Globe was markedly less resistant to storage loss than any of the others, the percentage of sound onions being significantly

less in this variety than in any of the others at the first two examinations. At the final examination there had been a rapid deterioration in Red Wethersfield and the difference between this variety and Yellow Globe was no longer significant. In all cases except Yellow Globe most of the loss of bulbs was due to Neck Rot. Specimens were taken at random from rotting bulbs and isolations made from the internal tissue. From 92% of the bulbs taken cultures of *Botrytis Allii* were obtained, and from the remaining 8% *Botrytis Cinerea* was obtained. In some cases rotting was associated with sprouting but it was not possible to determine whether the bulbs were infected before or after sprouting had started. Very few bulbs which were not infected with *Botrytis* showed premature sprouting except in the variety Yellow Globe. In this variety 44% of the bulbs discarded were sprouting but showed no signs of *Botrytis* infection. The leaves, however, all showed symptoms on onion virus disease.

(2). *Influence of Date of Lifting.* The effect of date of lifting on the loss of bulbs is summarised in Table II.

TABLE II.
PERCENTAGES OF SOUND ONIONS HARVESTED AT DIFFERENT DATES.

Date of Examination	Lifting Dates			S.E.	Differences required for significance	
	24.8.44	12.9.44	3.10.44		5% pt.	1% pt.
16.12.44	92.2	82.5	73.2	2.82	8.24	11.22
9.2.45	75.8	61.1	38.8	4.60	13.50	18.24
24.4.45	28.5	14.0	2.5	2.43	7.13	9.69

At all three examinations the percentage of sound onions from the first lifting date was significantly greater than in the onions lifted on 12.9.44. The percentage of sound onions from this lifting occasion was significantly greater than in the onions lifted at the final lifting date. All the varieties used reacted in the same way as is shown by the final percentage of sound onions of each variety from each lifting date given in Table III. The mean weights of the sound onions in pounds of each variety are given in brackets in the table.

TABLE III.
FINAL PERCENTAGE OF SOUND BULBS OF VARIOUS VARIETIES OF ONIONS LIFTED AT DIFFERENT DATES.

Date of Lifting	Bedford-shire Champion	Danver's Yellow Globe	Giant Zittau	Red Wethersfield	Rousham Park Hero	Up-to-Date
24.8.44	42 (5.0)	6 (0.25)	45 (5.5)	15 (1.25)	25 (3.0)	33 (4.0)
12.9.44	21 (2.6)	0 (0)	19 (2.5)	7 (0.75)	21 (2.5)	17 (2.5)
3.10.44	0 (0)	0 (0)	1 (0.1)	1 (0.1)	5 (0.6)	10 (1.25)

Note.—The figures in brackets are the mean weight in lb. of sound onions remaining from each sample of bulbs.

It can be seen that earliness of lifting caused less loss in all varieties tested and resulted in a higher weight of sound onions remaining at the end of the

experiment. Any loss in weight of crop due to early lifting was more than compensated for by the higher percentage of sound onions secured in the spring from the early lifted bulbs.

(3). *Influence of Storage Conditions.* The percentage of sound onions stored in the greenhouse and out of doors is shown in Table IV.

TABLE IV.
PERCENTAGES OF SOUND ONIONS STORED IN GREENHOUSE AND IN OPEN.

Date of Examination	Greenhouse	Out of Doors	S.E.	Difference required for significance	
				5% pt.	1% pt.
16.12.44	81.0	84.2	1.44	4.03	5.92
9.2.45	55.9	62.0	2.14	6.36	8.72
22.4.45	22.5	7.4	3.16	9.40	10.88

At the time of the first two examinations there was no significant difference in the percentage of sound onions in the greenhouse and out of doors. At the final examination the percentage of sound onions was significantly greater in the greenhouse than out of doors. This was probably due to the fact that out of doors the onions were exposed to a long spell of severe frost and later became extremely wet. It is possible that these very severe conditions caused the onions to decay more rapidly.

(4). *Effects of Fungicides on variety Bedfordshire Champion.* As can be seen from Table V none of the three fungicidal dusts used had any effect upon the amount of loss of bulbs of the variety Bedfordshire Champion.

TABLE V.
PERCENTAGE SOUND BULBS OF BEDFORDSHIRE CHAMPION TREATED WITH FUNGICIDES.

Date of Examination	Untreated Control	Sulphur	Tetramethyl-thiuramdisulphide	Trichlor-nitrobenzene	S.E.	Difference required for significance 5% pt.
16.12.44 ..	91.0	90.6	92.6	92.6	1.50	4.52
9.2.45 ..	62.6	62.0	62.0	66.0	2.22	6.69
24.2.45 ..	21.0	18.3	23.0	22.3	3.46	10.30

Discussion.

The outstanding result from this series of experiments is the effect of date of lifting upon the loss of onion bulbs. As was found by Wallace and Hickman (1) early lifting tended to reduce losses in storage. This suggests that infection of onion bulbs with *Botrytis* spp. is most likely to occur when the tops die off slowly, as normally happens with bulbs still in the soil. The advantages of early lifting are very definite in these experiments, but it seems that similar trials should be made in future seasons before it is possible to make a recommendation which is so contrary to the established practice in onion growing.

The subsequent storage conditions had less influence on loss of bulbs until after February 9th. After this date the onions exposed to external weather conditions deteriorated more rapidly than those kept in a greenhouse. These

two storage conditions, however, represent only two extremes and further investigation is required to test the effect of a range of conditions on the keeping qualities of onions.

Apart from the variety *Danver's Yellow Globe*, in which losses were very high as early as December 12th, there was surprisingly little difference in the losses in the varieties tested. It seems that the question of varietal resistance to loss in storage requires further investigation. These experiments also indicate that more information is needed on the connection between premature sprouting of onion bulbs and infection with *Botrytis* and Onion Virus.

Summary.

1. In the six varieties of onions *Bedfordshire Champion*, *Danver's Yellow Globe*, *Giant Zittau*, *Red Wethersfield* and *Rousham Park Hero* early lifting before the tops had died down resulted in significantly less loss of bulbs in storage.

2. Loss of bulbs was significantly greater in the variety *Danver's Yellow Globe* than in the other varieties.

3. Onions exposed to external weather conditions deteriorated more rapidly after February 12th than those stored in a greenhouse.

4. Treatment of bulbs with sulphur, a dust containing 50% tetramethylthiuramdisulphide and a proprietary compound containing trichloronitrobenzene had no influence on subsequent loss in storage.

Acknowledgments.

The author is grateful to Mr. C. J. Hickman for communicating to him before publication the results obtained in his experiments in 1943-4.

Thanks are also due to Miss J. Smith and Miss B. Iles, who gave much assistance in carrying out these experiments.

REFERENCE.

WALLACE, E. R. and HICKMAN, C. J. (1945). The influence of date of lifting and method of storing on loss of onion bulbs. *Annals of Applied Biology*, **32**, 200-205.

DOWNY MILDEW OF LETTUCE: FURTHER INVESTIGATIONS ON STRAINS OF *BREMIA LACTUCAE* OCCURRING IN ENGLAND.

By LAWRENCE OGILVIE.

In the Long Ashton Annual Report for 1943 (12) a description was given of some preliminary work on strains or races of the Downy Mildew of lettuce, *Bremia Lactucae*, occurring in England. Two strains were differentiated. The first, which will be designated Strain 1, infected readily Cheshunt Early Ball, Newmarket, Sutton's Imperial and May King, examples from four of the main groups of lettuce (2, 16), but did not infect (or infected only very slightly) Gotte à forcer, Loos Tennisball, Early French Frame and the so-called Blackpool strain of Early French Frame, *i.e.* various members of the Gotte group. The second strain of the fungus, Strain 2, infected all these varieties equally severely. The present paper briefly describes further investigations on the infectivity of these two strains, now collected from over twenty localities, to cultivated lettuce varieties, wild lettuces and certain related species. In

the infection experiments recorded, the results have been authenticated by many repetitions of each experiment.

Wild Lettuces and Related Species.

The wild lettuces mentioned in this paper, and certain other species in nearly related genera, may be tabulated as follows:—

<i>Lactuca Serriola</i> Linn	.. Prickly Lettuce	Europe and N.	Waste places
(= <i>L. Scariola</i> Linn)		America (introduced)	
<i>L. virosa</i> Linn	.. Wild Lettuce	Ditto	Ditto
(= <i>L. Serriola</i> var. <i>integrata</i> (Green and Godr.) Farwell)			
<i>L. muralis</i> Gaertn.	.. Ivy-leaved Lettuce	Europe	Old walls and rocky copses
<i>Sonchus oleraceus</i> Linn	.. Sow Thistle		
<i>Cichorium Intybus</i> Linn	.. Chicory		
<i>C. Endivia</i> Linn	.. Endive		
<i>Senecio vulgaris</i> Linn	.. Groundsel		

Strain 1 of *Bremia Lactucae*.

Host range. Strain 1, the specialised strain, was found on outdoor and indoor lettuces, but mainly on plants growing in the open. Infection experiments with this strain were carried out on wild lettuces by spraying spores on seedlings of *Lactuca Serriola*, *L. virosa* and *L. muralis* under the controlled conditions previously described (12). *L. Serriola* became infected, while *L. virosa* and *L. muralis* did not. Strain 1 did not infect Endive (Batavian and curled), Chicory, Groundsel or Sow Thistle.

From inoculation experiments with cultivated varieties of lettuce and from previous records the following list can be made of representative lettuce varieties susceptible and resistant to Strain 1.

Susceptible.—Arctic King, Attractie, Blatchford's Giant White Cos, Borough Wonder, Cheshunt Early Ball, Cheshunt Early Giant, Feltham King, Forcing Mildew Resistant (Watkins and Simpson), May King, Newmarket, Sutton's Imperial, Webb's Wonderful and Celtuce.

Resistant. Early French Frame (and "Blackpool" selection), Finney's 27, Gotte à forcer, Grand Rapids, Loos Tennisball.

Strain 2 of *Bremia Lactucae*.

Host range. Strain 2 was found on indoor and outdoor lettuces, but mainly on indoor lettuces. Infection experiments showed that it would not infect Endive, Chicory, Groundsel, Sow Thistle or *Lactuca muralis*, but it readily infected *L. Serriola* and *L. virosa*. This strain is generally infective to cultivated lettuces and all the varieties named in this paper have been found susceptible. No lettuce variety resistant to Strain 2 is at present known in Great Britain.

Strains of *Bremia Lactucae* previously known elsewhere.

Jagger (8), in 1926, tested 68 varieties of lettuces against a strain of Downy Mildew found near London. Of these, two French varieties, "Laitue passion blanche à grosse" and "Laitue de Saint Ilan," were found to be highly resistant or immune.

Macpherson (11), in 1932, in the course of trials of lettuce varieties in Lancashire, found that Loos Tennisball and Rosy Spring remained free from the disease and that May Queen was quite resistant, while Early French Frame became heavily infected. Golden Ball and Central Market Forcing were intermediate in susceptibility. It should be noted that these observations were made on mature plants in glasshouses and not on seedlings.



Fig. 1. Downy Mildew (*Bremia Lactucae*) on Prickly Lettuce (*Lactuca Serriola*).



Fig. 2. Downy Mildew on seedlings of Lettuce (Cheshunt Early Ball).

In America, Erwin (4, 5) found the Downy Mildew on *L. Scariola* var. *integrata* (= *L. virosa*) in Iowa and transmitted this strain to three wild American species and to 27 cultivated lettuce varieties (including May King, Tennisball, Iceberg and Grand Rapids), so that this strain was apparently of a generalised nature, similar to our Strain 2.

Jagger and Chandler (9) had differentiated, by 1932, three strains from California and Florida, to all of which "Romaine blonde lente à monter," a cos variety, was immune. In that year, however, another strain appeared which attacked all the varieties previously regarded as immune (10). It was found, however, that this last strain did not attack "Grosse blonde d'hiver Bourguignonne," and a race of *L. Serriola* obtained from Russia, and these were employed for breeding experiments with some of the immune varieties already produced and originally derived from crosses between "New York" types and French varieties.

It will be noted that Jagger and his associates made considerable use of French varieties both for the differentiation of their strains of Downy Mildew and for breeding new resistant varieties. These will be tested against the English strains of Downy Mildew as soon as seed can be obtained from France.

In Germany, Schultz and Röder (13) differentiated two physiologic races of *B. Lactucae*, one being non-pathogenic to four German varieties and the other attacking all varieties with equal severity.

Weed Infection by Lettuce Downy Mildew.

In Great Britain, two species of wild lettuce, *L. Serriola* and *L. virosa*, are able to act as hosts for *Bremia Lactucae*, and thus constitute a menace in the neighbourhood of market gardens. The specialised strain of *Bremia Lactucae* (Strain 1) has been found only on *L. Serriola*; while the more dangerous generalised strain, Strain 2, can attack both *L. Serriola* and *L. virosa**. These weeds, being biennials, can carry the mildew over from one year to the next. The leaves form a rosette, the lower surfaces retaining moisture and so providing conditions favourable to spore production even in dry weather.

The habitat given by Bentham and Hooker (1) for *L. Serriola* is "Dry and stony wastes, on banks and roadsides." In Somerset a large colony was discovered on the grassy bank of the Avon at Bath. Many of these plants were heavily infected with Strain 1 of *Bremia Lactucae*. *L. Serriola* has also been found in Somerset on a bomb-damaged site in Bath and spreading along railway cuttings near Taunton. Its habitat in the U.S.A. is described by Durst (3) as follows: "In waste ground, vacant lots, railroad rights of way, roadsides, etc., which environments furnish fairly dry rather than moist conditions."

L. virosa, which becomes infected with Strain 2, is closely related to *L. Serriola*, is similarly distributed and is found in similar habitats. It is also cultivated for the extraction of its milky latex, which supplies the medicinal drug "lactucarium." The writer has not yet found the Downy Mildew occurring naturally on *L. virosa*.

Breeding Resistant Varieties.

Lettuce (*Lactuca sativa*), *L. Serriola* and *L. virosa* all belong to the group of *Lactuca* species having 9 chromosomes (14), and cultivated lettuces have

* Mr. G. C. Ainsworth informs me that there are no British specimens of *B. Lactucae* on wild species of *Lactuca* in the Kew Herbarium and that there are no well authenticated records of such in British literature.

probably been derived from *L. Serriola* (3, 7, 14). The three species readily intercross and, as has been noted above, the group has been used for breeding mildew-resistant varieties in the U.S.A. In order to secure immune varieties of lettuces suitable for glasshouse forcing in England it would probably be necessary to embark on a breeding programme similar to that under way in the United States.

Summary.

1. Two strains or races of *Bremia Lactucae* on cultivated lettuces have been differentiated in England.

2. Strain 1 attacks *Lactuca Serriola*, but does not attack *L. virosa* or *L. muralis*. It also attacks lettuce varieties of many different groups, but does not attack Grand Rapids, a loose hearting variety, or certain members of the Gotte or forcing group.

3. Strain 2 attacks *L. Serriola* and *L. virosa*, but not *L. muralis*. It also attacks all the lettuce varieties tested.

4. The Downy Mildew has been found on *L. Serriola* growing wild. The wild lettuces therefore constitute a menace to neighbouring market gardens.

REFERENCES.

- (1) BENTHAM, G. and HOOKER, J. D. (Revised by Rendle, A. B.). *Handbook of the British Flora*. (Seventh Edition). Reeves & Co., 1937.
- (2) BRIAN, P. W. Varieties of Cabbage Lettuce and their Classification. *Jour. Pom. & Hort. Sci.*, **14**, p. 26, 1936.
- (3) DURST, C. E. Inheritance in Lettuce. *Univ. of Illinois Agr. Expt. Stn., Bull.* **356**, 1930.
- (4) ERWIN, A. T. Control of Downy Mildew of Lettuce. *Proc. Am. Soc. Hort. Sci.*, p. 161, 1920.
- (5) ERWIN, A. T. Controlling Downy Mildew of Lettuce. *Iowa Expt. Stn. Bull.*, **196**, 1921.
- (6) GEORGIA, ADA. *Manual of Weeds*. New York. The MacMillan Co., 1914.
- (7) HEDRICK, U. P. *Sturtevant's Notes on Edible Plants*. N. Y. Agr. Expt. Stn., 1919.
- (8) JAGGER, I. C. Lettuce Mildew. *Ann. Rept. Cheshunt Expt. Stn.*, for 1926, p. 35, 1927.
- (9) JAGGER, I. C. and CHANDLER, N. Physiologic Forms of *Bremia Lactucae* on Lettuce. *Abst. in Phytopath.*, **23**, pp. 18, 19, 1933.
- (10) JAGGER, I. C. and WHITAKER, I. W. The Inheritance of Immunity from Mildew (*Bremia Lactucae*) in Lettuce. *Phytopath.*, **30**, pp. 427-433, 1940.
- (11) MACPHERSON, N. J. Cultivation of Lettuce under Glass with special Reference to varieties resistant to Downy Mildew. *Journ. Min. Agr.*, **38**, p. 998, 1932.
- (12) OGILVIE, L. Downy Mildew of Lettuce. A Preliminary Note on some Greenhouse Experiments. *Ann. Rept. Long Ashton Res. Stn.*, 1943, p. 90.
- (13) SCHULTZ, H. and RÖDER, K. Die Anfälligkeit verschiedener Varietäten und Sorten von Salat (*Lactuca sativa* L. and *L. scariola* L.) gegen den falschen Mehltau (*Bremia Lactucae* Regel). *Züchter*, **10**, 7, pp. 185-194, 1938 (*R. A. M.*, **18**, pp. 7, 8).
- (14) THOMPSON, R. C. Further Studies on Interspecific Genetic Relationships in *Lactuca*. *Jour. Agr. Res.*, **66**, p. 41, 1943.
- (15) THOMPSON, R. C., WHITAKER, I. W. and KOSAR, W. F. Interspecific Genetic Relationships in *Lactuca*. *Journ. Agr. Res.*, **63**, pp. 91-107, 1941.
- (16) Salad Crops. *Min. Agr., Bull.* **55**, 1942.

CLOVER ROT INVESTIGATIONS.

A PROGRESS REPORT.

By MOIRA MUNRO and L. OGILVIE.

Clover Rot, caused by the fungus *Sclerotinia Trifoliorum*, has been known in the Bristol Province for many years; in some seasons a large number of cases are brought to the attention of the Advisor. Apart from field trials of varieties, which were carried out in collaboration with Mr. T. Walters Davies in 1935-36, little serious work on the disease has been carried out here as yet. In view of the increasing interest in ley farming in this area, however, it was

decided that a detailed investigation might be of value. Information on the course of the disease is available from the eastern counties, but little is known of its behaviour under the different climatic conditions of the south-west. The investigation is being furthered by parallel researches on Clover Sickness, due to the eelworm *Anguillulina dipsaci*, which are being carried out by Dr. A. J. Lloyd. Following is a brief report of progress to date.

Distribution and Seasonal Occurrence.

During 1944-46 the disease was identified from some twenty farms in north Hereford, south Gloucestershire (Cotswolds), the Cannington and Milverton areas of Somerset, and east Wiltshire.

Fields at Abson (south Glos.) and Chedzoy (Somerset) were kept under close observation. Early in March 1945, plants of Red Clover at both centres showed characteristic symptoms of the disease, the shoots wilting and turning brown and subsequently, under moist conditions, becoming covered with a web of mycelium. The fungus was isolated from these plants. When these fields and another at Badminton, Glos., were visited a few weeks later, practically all the Red Clover had been destroyed and a widespread infection of Trefoil (*Medicago lupulina*) was in progress. Many sclerotia were being formed around the crowns of dead and moribund plants and in the cavities of rotted stems. The soil in all these fields consequently had a high content of sclerotia during the subsequent season.

During the summer many of the infected crowns threw out new buds which gave rise to temporarily healthy shoots, so that by September there was a thin stand of clover again visible.

Since the three fields referred to were to remain unploughed throughout the winter a close watch was kept for apothecia arising from the sclerotia. Apothecia were found in large quantities during the first week in October at Abson and Chedzoy, over the whole area where infected clover had been observed in the spring. Production of apothecia continued at these two centres, and also at Badminton, throughout October, November and early December, and cultures of *S. Trifoliorum* were readily obtained by exposing agar plates for 30 seconds at 9 to 12 in. above ground level. It is remarkable, however, that up to the end of February no signs of initial infection became visible on the leaves of the resprouted Red Clover plants or on those of many kinds of Leguminous fodder plants in adjacent trial plots, though weather conditions appeared to be favourable to the disease, and leaf-spot fungi, *Stemphylium*, *Pseudopeziza*, *Dothidiella* and *Uromyces*, were abundant. Ascospores were viable and germinated almost at once even at low temperatures, as shown by laboratory tests, yet after 18 weeks no infection had apparently taken place in the field.

By December 11th apothecia at all the centres had decayed and no more were being produced. An occasional isolated plant had rotted but these cases were apparently due to systemic infection from the earlier attack in spring rather than to a fresh ascospore attack. The dead part of the crown, destroyed in spring, was clearly evident and infection appeared to have spread to the new summer shoots already referred to. Microscopic examination indicated that mycelium was present on the surface of the crown, in the base of the rotted shoots and on stipules, but none was found within the rootstock itself. Observations continued till mid-February, and despite frost and subsequent wet weather which might have been conducive to infection, practically no Clover Rot occurred.

Infection Experiments.

During the Autumn of 1945, when supplies of ascospores were available from apothecia collected in the field, many attempts were made to bring about infection experimentally on potted plants in the greenhouse and out of doors. The plants used were spring sown. The old straggling stems and leaves were usually trimmed back for convenience, but some were left deliberately to find whether the fungus required dead plant tissue on which to develop saprophytically before attacking healthy tissue.

In the first series, infection experiments were carried out by spraying a number of plants with a suspension of ascospores in water. In some cases the leaves were previously wounded with a hot inoculating needle. Three plants were inoculated with a spore suspension plus nutrient extract: four others were inoculated with a spore suspension containing parasitic eelworms and two plants with a mixture of other leaf spot fungal spores in the *Sclerotinia* ascospore suspension.

After being sprayed, the plants were usually kept in large deep pots, covered with glass, in which the atmosphere was maintained uniformly moist by a layer of wet peat at the bottom of the deep pot. After some weeks' incubation, the plants were taken out and placed on the greenhouse bench or out of doors. By January none of these plants showed any sign of infection. They were washed free of soil and incubated in moist chambers in the laboratory. In only two cases was *Sclerotinia* recovered from these artificially inoculated plants; one was a plant sprayed with spore suspension and eelworms and the other a plant sprayed with spore suspension and leaf spotting fungal spores.

A second series of experiments was made in October when groups of sclerotia bearing apothecia were inserted in the soil around four healthy clover plants in pots and placed in the covered moist chambers. At daily intervals the lid was raised and lowered to alter the atmospheric humidity and encourage the discharge of ascospores. Two of the four plants showed spotting of the leaves above the apothecia in 8 days time, and by December, after washing free of soil and incubating in the laboratory, three of the four plants treated showed *Sclerotinia* infection. This was found to be the most successful method for bringing about spore infection experimentally.

Attempts were made to induce infection by mycelium placed round healthy plants in the greenhouse and under field conditions, but without success. Nine-month-old plants were used and it is possible that these mature plants were resistant to attack. Further artificial infection was attempted during spring 1946, using young seedling clovers. The inoculum employed was a culture of the fungus growing on a wad of sterilised clover leaves. With this as food base it was found that the fungus was capable of attacking healthy plants under moist conditions. Infection occurred readily when a wounded petiole was placed in contact with the inoculum.

Possible Seed Infection.

It is possible that spring outbreaks on land where clover crops have not been grown for many years may arise from infection of the seed. This matter is at present under investigation. It is known that first year leys are more frequently attacked than clover in the second year of growth. Isolated plants in several first year ley plots at Cannington showed Clover Rot infection while those around remained healthy. These facts suggest the possibility of the fungus being seed-borne. Samples of seed from Clover Rot fields were collected in Autumn 1945. Seeds derived from two farms, surface sterilised and plated

on agar plates have produced cultures of a fungus resembling *Sclerotinia trifoliorum*. This would indicate that the fungus may exist not only as sclerotia present in the seed sample but actually within the seed itself. Before any definite claim can be made on this point further confirmation is required.

Possible Extraction of Sclerotia from Soil.

During the course of the investigation an attempt was made to develop a technique for extracting sclerotia from soil samples. It was thought that such a technique would enable a report to be made in advance on the chances of failure due to *Sclerotinia*. Soil samples were shaken up with water and with other liquids of specific gravity slightly less than that of soil and allowed to settle out, but owing to the specific gravities of soil and of the sclerotia being very similar, they could not be induced to float to the interface of the liquid. Many sclerotia were recovered from the surface of soil and water, but some always remained buried in the sediment. No accurate estimate of the sclerotial content of soil could therefore be obtained by this means and the project was set aside.

Discussion.

Although it would be unwise to base any conclusions on observations made during one year only, it does appear that in the south-west there are several peculiar aspects of the problem. If infection takes place mainly by ascospores, why are outbreaks of Clover Rot comparatively few in number and slow to appear in the neighbourhood of fields where ascospores are shed, and why does not infection occur when conditions are apparently favourable? The roles of seed-infection and of spread of mycelium from plant to plant in bringing about new outbreaks and epidemics have to be investigated more fully, while the possible relationship of infection to previous or concurrent infections with other fungi and with the clover eelworm deserve attention.

TECHNIQUE FOR THE STUDY OF CLOVER STEM EELWORM, *ANGUILLULINA DIPSACI*, KUHN.

By A. J. LLOYD.

As part of a series of studies of the incidence of eelworm pests in farm and market garden crops that are being carried on in the Provincial Advisory Entomologist's section at the Long Ashton Research Station some preliminary work has been completed on the parasitism of red clover by the clover stem eelworm, *Anguillulina dipsaci*, Kuhn (1).

The development of a method of assessing the level of intensity of eelworm infestation in field soils.

Experiments were started in 1944 to find out whether, for the purpose of giving advice to farmers, field soils could be classified according to the intensity of attack by parasitic eelworms on red clover grown in them. One hundred seeds of certified Montgomery late-flowering red clover were sown in a 12-inch pot containing soil from a field known to be heavily infested with eelworms and in which red clovers had completely disappeared during the first winter after seeding. There was a good emergence of seedlings, of which many were deformed and the majority showed considerable swelling of the hypocotyl

region, often accompanied by malformation or loss of cotyledons (2). The path of entry of the eelworm into the seedling was usually marked by a line of brown cells, and eelworms were frequently observed entering the tissue through the epidermis in the region of the hypocotyl. The seedlings were dissected under a binocular microscope and eelworms were found in many that had no visual symptoms of infestation. Examination of seedlings showed that eelworms were present in 30% by the time they had completely emerged above the soil. Since the area of the pot was small and it was difficult to distribute the seeds evenly, seed boxes were later used. The boxes were approximately 12" x 16" and were filled to a depth of 2" with soil. Since it was essential that each seedling should be exposed to a similar infestation the soil was well mixed before being placed in the boxes. Even spacing of the seeds was secured by using a sheet of wood with holes drilled at one inch intervals, each three holes forming an equilateral triangle. A seed was dropped through each aperture. Seed boxes with similar seed sown in sterilised soil were always maintained concurrently as controls to ensure that seed-carried infestation did not confuse results. When boxes were kept out of doors, the period before emergence of the seedlings was found to vary greatly with the temperature, and to secure speedier germination the boxes were placed in a hothouse. In the greenhouse the first seedlings showed in approximately seven days. After emergence each seedling was removed from the soil carefully, washed with clean water to remove any eelworms on the exterior, and then placed on a glass slide with a little water for examination and dissection.

This biological method of testing soils for eelworm infestation was used in 1945 for the purpose of assessing the risk of eelworm attack on red clover in agricultural soils and for indicating the level of infestation of eelworm in fields where clover has failed. It was also used as a means of furnishing data on the resistance of various clovers to eelworm attack.

The results of a number of tests for level of infestation are shown in Table I.

TABLE I.
EELWORM INFESTATION OF MONTGOMERY CLOVERS IN FIELD SOILS.

Centre	No. plants examined	No. plants infested	Eelworms/ infested plant
Chedzoy	50	22	2
Butleigh	50	44	8
Milverton	50	6	1
Wellington	50	5	1
Watchet	50	6	1
Williton	50	0	0

Since eelworms invade the seedlings immediately after germination it is essential that they be examined soon after their emergence, before the eelworms have had time to multiply. The eelworms recorded in Table I were pre-adult infective larvae and adults. In Chedzoy and Butleigh soils the levels of infestation was high whether measured in terms of percentage of seedlings attacked or intensity of seedling infestation. In both cases the soil was from fields where no regular rotation was followed and red clover had been grown

three times in five years. The test of Wellington soil (Table I) gave 10% infestation of seedlings. From these preliminary tests it was evident that the biological method gave evidence of soil infestation by eelworms and could be used to forecast the intensity of eelworm attack on clover. The accuracy of the test depends largely in the method of sampling the soil. Forty or preferably eighty augur-samples should be taken at random over the field and should be bulked and well mixed. Where eelworms are sufficiently numerous to cause appreciable loss of clovers in the field this method of sampling gives a reliable indication of eelworm intensity, but in fields with low eelworm populations the sample may fail to show the presence of eelworms since their distribution may be uneven. From a comparison of the condition of seedlings in sampled fields it seems that when 10% of the seedlings in the test sample are infested fairly severe attack may occur in the field. When over 30% of the seedlings in the test sample are infested there is serious risk of complete loss of crop.

TABLE II.

Variety or Strain	No. plants examined	No. plants infested	Eelworms/ infested plant
Broad Red Clovers			
S 151	11	6	2
New Zealand	9	7	2
Dorset Marl	22	13	1
American	20	7	3
Essex	16	9	2
Canadian	20	6	1
Altaswede	23	11	2
Late Flowering Red Clovers			
Montgomery	20	5	1
S 123	25	12	3

On the relative infestation of selected red clovers.

The data given in Table II were obtained by sowing various broad red clovers and late-flowering red clovers in infested field soil from Chedzoy and in artificially heavily-infested soil obtained as previously described. There were no significant differences in the behaviour of different clovers under similar intensities of attack (3), and both broad red clovers and the late-flowering red clovers were equally attacked in a natural soil infestation that affected from 40% to 52% of the seedlings.

Eelworm attack and root nodule development.

Noticeable lack of root development is one of the important external symptoms of stem eelworm attack on clovers. Twenty-five seedlings in each of six age groups have been measured from the base of the hypocotyl to the tip of the root and these measurements of growth have been grouped and related to the intensity of eelworm attack (Table III).

In growing from 25 mm. to 70 mm. a healthy plant normally forms 6 laterals. At the same time it produces four nodules, usually on the tap root

TABLE III.

Length group of plant	Red clovers attacked by <i>Anguillulina dipsaci</i> .				Red clovers not attacked by <i>Anguillulina dipsaci</i> .			
	No. plants examd.	laterals/ plant	nodules/ plant	eelworms/ plant	No. plants examd.	laterals/ plant	nodules/ plant	eelworms/ plant
20-29 mm. . .	25	2.1	3	17	25	3	3	0
30-39 mm. . .	25	2.4	3	25	25	5	4	0
40-49 mm. . .	25	1.7	3	7.4	25	6.2	3	0
50-59 mm. . .	25	2.4	3	2	25	8.8	4	0
60-69 mm. . .	25	2.6	3	2	25	8.4	5	0
70-79 mm. . .	25	3.0	3	1.5	25	9	7	0

but sometimes on laterals. An eelworm-infested clover seedling does not produce the normal number of laterals or nodules. The suppression of the root system has a serious effect on the growth of the plant and petiole lengths are similarly affected. At the end of the first year plants attacked after the seedling stage also show a reduction in the number of nodules although the lateral roots may be fairly strongly developed. The loss of nodules will affect the capacity of the clover root to restore fertility between barley crops. In addition there will be a related loss of the clover constituent in the hay. It has been noticed that there is a marked lack of humus in Somerset soils in which eelworms are present and this lack may be associated with poor clover crops following persistent eelworm attack. It seems likely, therefore, that loss of fertility, both directly as nitrogen and indirectly as humus may occur where red clover is grown in a close rotation in soils heavily infested with the clover stem eelworm.

Summary.

1. A description is given of a biological method of assessing intensity of eelworm attack in field soils. Its use in forecasting loss of red clovers in leys is described.

2. None of the red clovers examined are immune from attack and there is little difference in their susceptibility. Initial attack by adult and pre-adult eelworms at seedling emergence seems related to the eelworm population of the soil.

3. Eelworm attack is followed by a reduction in the number of lateral roots and root nodules. It is suggested that this may result in a reduction of clover in hay and in a smaller bulk of clover-root when infested leys are ploughed.

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REFERENCES.

- (1) AMOS (1918). *Journ. Royal Agric. Soc.* LXXIX, p. 68.
- (2) GOODEY (1922). *Journ. Agric. Science.* XII, p. 20.
- (3) HODSON (1926). *Ann. App. Biol.* XIII, p. 219.

EELWORM PESTS AND COMMERCIAL VEGETABLE PRODUCTION.

By HERBERT W. MILES and MARY MILES.

Eelworm pests are among the most important of the long list of injurious organisms that threaten successful vegetable production in established market garden areas. In recent years crop sickness and eelworm parasites have become increasingly widespread, and in some districts major crops have appeared to fail suddenly or yields have been persistently poor. War-time cropping restrictions have limited the range of crops that could be grown and prevented any appreciable widening of rotations. The supply of fertilizers and artificial manures has been insufficient to meet demands and the shortage has seriously affected fertility in some market garden areas, but high prices and established practice have resulted in the continuance of the accustomed series of crops in spite of declining yields. The demand for certain vegetables has increased and cauliflowers and peas for canning have been grown successfully on a farm scale in districts previously devoted to traditional agricultural crops. There are already signs that the success of vegetable crops on farms may lead to the development of crop sickness on a farm scale unless there is a greater awareness of the seriousness of eelworm pests and of the conditions under which they occur.

Eelworms Attacking Vegetable Crops.

The potato root eelworm, *Heterodera rostochiensis* Woll., which attacks potatoes and tomatoes, is probably the best known of the eelworms parasitic on vegetable crops. In 1939, on the outbreak of war, all restrictions on potato-growing were removed and county war agricultural committees were empowered to extend the acreage under potatoes. Rotations were shortened in districts where potatoes were already widely grown, and the number of fields showing obvious signs of potato sickness and eelworm infestation speedily increased. Fields where potato sickness was being eliminated by resting under grass and stock were again broken for potatoes, and the success of potatoes in districts new to potato-growing encouraged close cropping and has resulted in the establishment of the eelworms in new areas.

Potato root eelworm is also a major pest of tomatoes under glass (Johnson and Thompson, 1936). Glasshouses for tomatoes have been erected on land with a history of potato-sickness, and the practice of using old market garden soil to replace the exhausted soil of glasshouses has helped to distribute the pest. Infestation of tomatoes may take place while the plants are in the seedling stage or later when they are set out in their permanent sites. Attacked plants make slow progress and wilt readily, and the check to growth that follows even slight infestation by potato root eelworm greatly affects the value of the crop. Tomatoes grown in the open in soil infested with potato root eelworm are also attacked.

Pea eelworm, *Heterodera gōttingiana* Lieb., invades the roots of peas, beans, clovers and vetches, and is well established in gardens in Southern England, in the Midlands and in South Wales. It is widely distributed in the market-garden area of Worcestershire (Walton *et al* 1933) and occurs on a field scale in Somerset, Wiltshire and other counties where peas are grown as a field crop. Observations (Franklin 1939) suggest that cyst-forming eelworms

of *Heterodera* may be widely distributed on the roots of clover in agricultural soils, and the appearance of pea eelworm in fields after the cultivation of a few crops of peas for canning suggests that pea-infesting species of eelworms may be present in the soil before peas are grown. In 1945 in Wiltshire the writers examined a first crop of peas for canning. The crop showed characteristic signs of pea sickness (Powell 1939) although peas had not been grown previously. Eelworm cysts were numerous on the roots and examination of the soil revealed a cyst population of 20 viable cysts per 10 cc. of air-dried soil. Enquiries regarding the rotation elicited that clover for hay and spring vetches had occupied the ground three seasons out of five for practically twenty years and that the last crop of vetches had not been satisfactory, and it seemed probable that previous crops of clovers and vetches had built up the eelworm population. Since the cultivation of peas for canning is likely to extend in certain areas farmers and their advisers should review the history and performance of fields proposed for this crop, and should avoid those where indifferent success of clovers and vetches suggests the possibility of incipient pea sickness. The possibility that pea eelworm is already present in fields where clover ley has been a feature of the crop rotation should deter new growers from close cropping with peas.

Beet eelworm, *H. schachtii* Schmidt, is locally a pest of spinach, beet and brassica crops in market garden areas, and the brassica eelworm, *H. cruciferae* Franklin, is another potential pest of cultivated *Brassicae*. At present these eelworms are not of major importance in vegetable production, but their occurrence in various parts of the country has been recorded (Monthly Reports, Ministry of Agriculture).

Root-knot eelworm, *H. marioni* Cornu, a semi-tropical species widely established in glasshouses in Britain, has an extensive range of host plants and has been found locally out of doors (Monthly Reports, Ministry of Agriculture) on carrots, parsnips and lettuce. Though climatic conditions may prevent its general distribution, its persistence out of doors in a few localities suggests that it is a potential pest of vegetable crops in sheltered places where it can withstand the winter climate.

Stem and bulb eelworm, *Anguillulina dipsaci* Kuhn, differs from the *Heterodera* eelworms already mentioned in that it does not form cysts but remains worm-like, and feeds and breeds in the host plants through the year. The eggs are laid in the plant tissue, and all stages from eggs to mature eelworms are found together. The stem eelworm appears to be a general feeder. It attacks potatoes, cereals, leguminous crops, brassicas, beet, onions and innumerable flower crops, including narcissi and phlox. Attacks on vegetable crops are sporadic and the conditions under which they occur are little understood, but there is much to suggest that the presence of stem eelworms is associated with continuous cropping with a narrow range of crops. Under favourable conditions strains of *Anguillulina dipsaci* may become highly specialized on certain host plants (Fox Wilson 1943), and common weeds such as chickweed and cleavers (Staniland 1945) also sustain the eelworms. Stem eelworm is of considerable importance in old arable land where it is associated with clover sickness and with tulip-root of oats, and when vegetable crops are grown on plough-sick land some strains of eelworms may prove capable of adapting themselves to the new crops (Hodson 1926). Stem eelworms invade potato tubers and cause discoloured patches on the surface while the interior tissue of attacked potatoes becomes dry and mealy; infested tubers rot when stored for winter. Eelworm attack on onions causes "bloat," a swelling and

thickening of the leaves and bulb, and is followed by rotting which may not be evident until after the onions have been stored. Eelworm canker of parsnip, a galling and rotting of the upper part of the tap root, rotting in carrots, and diseased conditions in peas and beans are also associated with attack by the stem eelworms.

Persistence of Eelworms.

A characteristic of eelworms is their ability to persist for long periods in the absence of their host plants. Emergence of eelworms from encysted eggs of *Heterodera* spp. is retarded by the absence of the host plant and soil infested with potato root eelworm which was maintained under rotational cropping without potatoes for eight years has been found to contain viable cysts (Miles 1942). The stem eelworm also is highly resistant to starvation and drought. When exposed to drought while within the host plant tissue it curls like a watch spring and becomes inactive, and it has been observed to revive after a quiescent period exceeding six years (Goodey 1933).

Conditions leading to Eelworm Infestation.

The potato root eelworm, *Heterodera rostochiensis*, Woll., is present in all established potato-growing areas and occurs throughout Britain in allotments and gardens. It has been under observation almost continuously for over twenty years and much is known of its distribution and the conditions under which it occurs. It is now recognised that potato root eelworm becomes established wherever close cropping with potatoes or tomatoes is maintained for some time. This eelworm does not appear to be indigenous in Britain and is not part of the natural soil fauna here, but is transported from place to place as cysts in soil about seed tubers, seedlings, implements, boots of workers, market refuse, and in wind-blown soil and drainage water. A common source of infestation appears to be at the bottom of sacks in which potato seed tubers are distributed, and consequently the more frequently seed tubers are planted the more frequently is clean land exposed to the risk of eelworm infestation. Once potato root eelworm cysts are introduced to a new site their rate of multiplication and spread is determined by cropping. As long as no potatoes or tomatoes are grown the eelworms cannot multiply, but when suitable host plants are set young eelworms emerge from viable cysts and invade the crop. After feeding for 4–6 weeks they reach maturity and form new cysts to carry attack to subsequent crops. The number of infective cysts is greatest immediately after a host crop has been grown and gradually declines in the absence of host plants (Miles 1942). The shorter the interval between potato crops the greater the number of viable cysts capable of releasing eelworms to infest the new crop and the more rapidly a high eelworm population is built up. When long intervals occur between potato crops accidental infestations may fail to become established or the eelworm population may increase so slowly that its numbers remain negligible and its presence may not be detected.

Observations by Petherbridge, Stapley and Thomas (1938) show that the presence of high populations of beet eelworm, *H. schachtii*, Schmidt., is similarly associated with close cropping with beet and mangolds. In the field where these observers first found beet eelworms on sugar beet there had been ten crops of beet and mangolds in fourteen years. Severe infestation of swedes by beet eelworm has been observed where swedes were grown alternately with beet, and where swedes and other *Brassicæ* occurred frequently in a

short rotation (Roebuck, Monthly Reports, Ministry of Agriculture, 1936, 1937). Eelworm infestation of turnips has been recorded (Hodson, Monthly Reports, Ministry of Agriculture, 1937) when turnips were grown in alternate years. It has been shown (F. G. W. Jones 1945) that as with potato root eelworm, the infestation potential of beet eelworm, measured by the numbers of eggs in the soil, is greatest immediately after a host crop and declines during the succeeding seasons so long as no host crop is grown.

As with potato root eelworm and beet eelworm the presence of high populations of pea eelworm are associated with close cropping with host crops. In gardens peas and beans are among the most popular vegetables and are frequently grown year after year on the same site. On many market gardens the range of crops is small and close cropping is common, and pea eelworm is established on holdings where peas have been a major crop for some time. Peas for canning and for selling green have proved to be a remunerative crop in certain agricultural districts and where several crops have occurred in rapid succession pea eelworm has become a serious pest.

Factors Causing Crop Sickness.

The presence of plant-parasitic eelworms is generally associated with characteristic signs of crop sickness. Affected crops become yellow and stunted in patches which may be so extensive as to include practically the whole field. In crop sick areas root development is poor and crops like potatoes, tomatoes, beet, swedes and turnips produce many thin fibrous roots, and their yields are usually negligible.

Crop sickness is a complex condition to which soil fertility, climate and parasitic organisms contribute, and the importance of each factor varies with the field and the season. Signs are usually most pronounced where arable crops have been grown for a long period. In such circumstances the soil surface is bare and exposed for much of the year, surface cultivations are frequent, and continuous cropping with a narrow range of crops makes heavy demands on available plant food. In cases of exhausted fertility the missing elements are not always restored in a form immediately usable by plants, and continuous cultivation and loss of humus is associated with a gradual breakdown of soil structure.

The importance of the fertility factor in crop sickness is indicated by the improvement in health and vigour following the application of fertilizers to potato sick land. The choice of fertilizer is necessarily affected by soil type and previous manurial history. In the peat soils of South Lancashire and North Cheshire and the silt soils of South Lincolnshire farmyard manure and nitrogenous fertilizers like sulphate of ammonia, calcium cyanamide and gas works liquor (= 40 cwt. sulphate of ammonia per acre), have alleviated potato sickness and increased the yields; in Devon and Cornwall (Blenkinsop 1935) on soils rich in phosphate similar results followed the application of potash; and in Worcestershire pea sickness was reduced by a dressing of organic phosphate in the form of ground hoof and horn, while farmyard manure increased the signs of sickness by encouraging the development of foot rot disease (Walton *et al* 1933). It has also been frequently recorded that when a high state of soil fertility is maintained, characteristic signs of sickness may be absent from potato crops heavily infested by parasitic eelworms.

The contribution of eelworm parasites to crop sickness is recognized. The eelworms invade the plant tissue to feed, and when a large number of eelworms enter the same region simultaneously vital plant tissue is destroyed.

When the environment is sufficiently favourable to maintain vigorous growth plants can sustain heavy eelworm attack without developing marked pathological symptoms, but if growth is retarded by climatic conditions or lack of available plant food a slight or moderate invasion by eelworms may be associated with symptoms of crop sickness. Other parasitic organisms also contribute to the crop sickness complex. Attack by pea eelworm is associated with the occurrence of the foot rot fungus, *Fusarium* sp. and *Corticium solani* is usually present with eelworms on potatoes.

Climatic conditions may be of considerable importance in the plant—eelworm relationship. When climatic conditions favour the early establishment of the plants they may be able to withstand eelworm attack, but when plant growth is checked by frost or other adverse weather factors the delay may enable the rate of destruction by eelworms to overtake the rate of growth and so prevent the crop from making satisfactory progress during the normal growing season.

Progress of Research on the Control of Eelworms.

The close association between the presence of parasitic eelworms and the occurrence of crop sickness has confused the problem of eelworm control and has made the interpretation of field experiments difficult. Substances intended to affect eelworms have had such marked effects on the host plants that the effects on the eelworm parasites have been obscured or neglected, and treatment that produced healthier plants and better yields has been regarded as giving satisfactory control of eelworms irrespective of its effects on their numbers. In recent work the alleviation of crop sickness and the eradication of eelworm parasites from the soil have been recognized as distinct and separate problems, but field experimental work on the control of eelworms is still carried on in circumstances where lack of fertility is a major factor in the plant environment.

Field experiments on potatoes on crop-sick land have shown repeatedly that plant health can be improved and yields increased by the application of manures and fertilizers and by the partial sterilization of the soil by chemical means. Observations on the effects of such treatments on the eelworm population of the soil have shown that improvements in the health of the plants are generally associated with increases in the eelworm population (Buckhurst and Fryer 1931), probably because the greater bulk of root tissue produced by larger and more vigorous plants enables greater numbers of eelworm parasites to reach maturity.

In Britain research work on direct control of eelworms has mainly concerned potato root eelworm, and both biological and chemical means of control have been studied. Laboratory experiments (Morgan 1925; Triffitt 1929, 1930) have shown that the hatching of eelworms from cysts can be delayed or partly inhibited by the incorporation of mustard plants with the soil, but field experiments have given disappointing results (M. Mac M. 1932). It appears that the use of mustard as green manure on potato sick land may give a temporary protection from eelworm invasion, but the inhibitory effect of mustard on eelworm emergence is soon neutralized by the stimulation to hatching afforded by the potato crop. Allyl isothiocyanate, the essential oil of black mustard, *Brassica nigra* L. has been shown (Ellenby 1945, i) to have an inhibitory effect on the emergence of eelworms from cysts but, nevertheless, under the influence of secretions from potato roots, eelworms emerged from cysts that had been exposed to allyl isothiocyanate concentrations of 1/20,000

and 1/1,000,000. The substance has also been used in small-scale field trials (Ellenby 1945, ii), but results were measured in terms of yield and no observations on the eelworms were recorded. In view of the failure of allyl isothiocyanate at a concentration of 1/20,000 to inhibit hatching from cysts in laboratory experiments, it seems unlikely that a dressing of 0.1 cwt. per acre (approximately 1/400,000) would have more than a temporary effect on eelworms in the field, and that the increase in yield was probably the result of a short period of protection from eelworm invasion at the beginning of growth.

Consideration has also been given to the possibility of eliminating eelworms from infested soil by stimulating their emergence from the cysts prior to growing potatoes. Investigations (Triffitt 1934; Franklin 1937) suggest that the cultivation of maize and the meadow grasses (*Poa* spp.) may appreciably reduce the infestation potential of eelworm cysts in the soil. Data so far collected, however, do not show clearly how far the reduction of eelworm infestation potential by means of these plants exceeds that occurring normally (Miles 1942; F. G. W. Jones 1945) when cysts in soil are exposed to the effects of cultivation, cropping and weather.

The use of trap crops of potatoes to reduce the eelworm infestation of the soil has also been investigated (Carroll and McMahon 1939), and the results of experiments suggest that two trap crops of potatoes are sufficient to effect an appreciable reduction. This method of control necessitates the complete removal of the trap crop before any eelworms reach majority on it, and lifting must be done so carefully that no tubers or roots are left to maintain the eelworms. Cropping with potatoes should then be delayed until the following season so that free eelworms perish (Franklin 1937) before the crop is planted. This method of reducing eelworm infestation is perhaps suitable for adoption on allotments and gardens, but is scarcely practicable for use on a field scale.

Laboratory experiments have shown that a number of chemical substances affect the hatching of eelworms from cysts, and that the concentration at which they are used may determine whether emergence of eelworms is stimulated, delayed or inhibited. Laboratory and field trials have been mainly concerned with calcium cyanide (Miles & Turner 1928), calcium cyanamide and ferric oxide (Edwards 1929, 1937; Hurst and Triffitt 1935, 1937; Hurst and Franklin 1937; Miles 1930); ammonium and calcium chloroacetates (Smedley 1938; Edwards 1939; Gemmell 1939), and phenyl isothiocyanate (Smedley 1939). When used at sufficiently high concentrations these substances have been effective in reducing the eelworm infestation of potatoes grown in pots and in small plots, but there are many obstacles in the way of their use in the field. Heavy dressings are required to reduce the eelworm population to an appreciable extent and most of the substances tested are not available in sufficient quantity for general use. All are costly, the toxic dressing of calcium chloroacetate having been estimated to cost in 1940 about £60 per acre, and a suitable quantity of phenyl isothiocyanate has been described as "prohibitive" (Leiper 1940). All are also markedly phytocidal when used at rates necessary to give control of eelworms and their use would interfere at least temporarily with the routine of cultivation and cropping. The even and thorough incorporation of chemical substances with field soils to a depth equal to that penetrated by the roots of the host plants presents special difficulties that will have to be overcome before control measures involving the application of chemicals to the soil can be generally recommended.

A soil fumigant, Shell D.D., a mixture of dichloropropane and dichloropropylene, has been used experimentally in America against eelworms parasitic

on plants (Shell C. Bull. No. 3). Results so far available seem insufficient to determine whether, at the concentrations used, the fumigant acts mainly as a stimulant to plant growth or as a toxic agent against eelworms. When the fumigant is available for use in this country attempts should be made to assess the value of these two functions separately.

In the absence of suitable chemical or biological control measures an attempt has been made to check the development of beet eelworm, *H. schachtii* Schmidt, and the spread of beet sickness by legislative measures. The aim of legislation has been to establish a wide rotation on land known to be infested with beet eelworm. The soil of suspected fields has been examined and the minimum interval between susceptible crops determined by the eelworm infestation potential of the soil as indicated by numbers of viable eggs. This method of limiting the development of high eelworm populations and preventing the spread of beet sickness by the regulation of cropping has undoubtedly been effective in maintaining yields of sugar beet in areas in the East of England where the crop is grown intensively.

Eelworm Control and Cropping Policy.

Enough is now known of the incidence of crop sickness and eelworm infestation in commercial vegetable crops to associate their occurrence with some neglect of basic conditions of good husbandry: the maintenance of soil fertility and the adoption of suitable crop rotations. Most farmers and growers are already aware of the weakness inherent in their systems of culture, but economic and other factors have determined cropping practice and encouraged narrow specialization, and loss of dung through the mechanization of cultivation and transport has been a major factor in the deterioration of soil fertility in many market garden areas.

The demand for direct control measures against eelworm pests comes mainly from growers who wish to continue specialized cropping or to cultivate in a narrow rotation those very crops that have raised the population of parasitic eelworms to dangerous levels. These growers do not appreciate fully the limitations and difficulties attendant upon the direct control of organisms like eelworms which have an enormous capacity for rapid multiplication. It has been shown (Miles 1942) that a viable cyst population of 1 per 100 cc. of air-dried soil was increased to 94 per 100 cc. by two heavy crops of potatoes even though an interval of three years intervened, and under certain conditions this latter cyst population is sufficiently high to be a danger to subsequent crops. It should therefore be realized by growers and their technical advisers that a reduction of the eelworm population by highly efficient control measures may be completely neutralized by one or two successful crops, and that if the practice of close cropping with susceptible crops is maintained on soil once infested with eelworms direct control measures, however costly, will have to be regarded as part of the routine of production.

Both cropping policy and future experimental work on the control of eelworms should take into account the close relationship between the vigour of the host plant and the intensity of eelworm infestation in soil where eelworms are established. Experience has shown that eelworm populations tend to be stable where yields from their host crops are stable and to fluctuate under conditions where, through attack by parasites, changes in the level of fertility, adverse climatic and other factors, yields from host crops fluctuate.

The interrelation of crop vigour and the number of eelworms reaching maturity on the crop makes it difficult to determine the level to which the

effective eelworm population should be reduced to constitute satisfactory control. In soil heavily infested with potato root eelworm it is not unusual to find viable cyst populations of 8-10 cysts per cubic centimetre of soil. A high degree of toxic efficiency would be necessary to reduce such populations to a negligible level, and treatment would have to be repeated after each successful host crop if a low eelworm population was to be maintained. It may therefore be advisable to initiate research work on the maintenance of satisfactory yields from eelworm-infested crops, accepting in such circumstances the presence of parasitic eelworms as an unavoidable factor in the crop environment which must be neutralized by greater attention to fertility and cultural conditions.

The most practical and economical measure for preventing the development of high eelworm populations and avoiding loss from crop sickness appears to be the adoption of a wide rotation and the maintenance of a high level of fertility. Every possible precaution should also be taken to prevent the spread of eelworms, a matter which in the case of potato root eelworm would involve some control of the production and sale of seed potato tubers.

Where eelworm populations are already high widening the rotation offers the most practical means of decreasing the eelworm infestation potential of the soil prior to growing susceptible crops. From a national point of view there is much to be said for putting into practice in many market garden and intensively-cropped areas a comprehensive system of restorative husbandry, with livestock or poultry and leys as the principal agents of recuperation. Such crops as potatoes should cease to be localized and become more widely distributed over the country with a recognized place in farm rotations, for war-time experience has shown that they can be grown successfully in many districts. Where vegetable production on a field scale has become part of farm practice the land on which vegetables are grown should be subject to a wide rotation in which closely related farm crops have no place, and it should be allowed to rest and recuperate periodically under grazed leys.

Where local values demand the retention of intensive systems of husbandry the possibility of introducing short-term crops of soft fruits should be considered, and such crops as asparagus and rhubarb, and flowers like pyrethrums and paeonies might also be used to widen rotations. The heavy manuring with organic manures necessary to keep these suggested crops in successful production would ensure some measure of restoration of fertility.

REFERENCES.

- BLINKINSOP, A. (1935). Observations on potato-sick soils in Devon and Cornwall. *J. Min. Agric.*, XLI, 1187.
- BUCKHURST, A. S. and FRYER, J. C. F. (1931). The problem of "potato sickness." *Ann. appl. Biol.*, XVIII, 584.
- CARROLL, J. and McMAHON, E. (1939). Experiments on trap cropping with potatoes as a control measure against potato eelworm. *J. Helminth.*, XVII, 101.
- EDWARDS, E. E. (1929). The control of a serious potato trouble. *J. Min. Agric.*, XXXVI, 234.
- EDWARDS, E. E. (1937). Field experiments on control of "potato-sickness" associated with the nematode, *H. schachtii*. *J. Helminth.*, XV, 77.
- EDWARDS, E. E. (1939). Fields tests on the value of calcium chloro-acetate for controlling the potato-sickness associated with the root eelworm, *H. schachtii*. *J. Helminth.*, XVII, 51.
- ELLENBY, C. (1945). The influence of crucifers and mustard oil on the emergence of larvae of potato root eelworm, *H. rostochiensis* Woll. *Ann. appl. Biol.*, XXXII, 67.
- ELLENBY, C. (1945). Control of potato root eelworm *H. rostochiensis* Woll. by allyl isothiocyanate, the mustard oil of black mustard, *Brassica nigra* L. *Ann. appl. Biol.*, XXXII, 237.
- FRANKLIN, M. T. (1937). Effect on cyst contents of *H. schachtii* of cultivation of maize on potato-sick land. *J. Helminth.*, XV, 61.
- FRANKLIN, M. T. (1937.) The survival of free larvae in soil. *J. Helminth.*, XV, 69.

- FRANKLIN, M. T. (1939). Natural infections of *H. schachtii* on clovers in Britain. *J. Helminth.*, XVII, 93.
- FRANKLIN, M. T. (1945). On *Heterodera cruciferae* n. sp. of brassicas and on a *Heterodera* strain infecting clover and dock. *J. Helminth.*, XXI, 71.
- FOX WILSON, G. (1943). The stem and bulb eelworm, *Anguillulina dipsaci* (Kuhn 1858): the importance of collating evidence on the behaviour of biologic strains. *Ann. appl. Biol.*, XXX, 364.
- GOODEY, T. (1933). *Plant Parasitic Nematodes*. Methuen, London.
- HODSON, W. E. H. (1926). Observations on the biology of *T. dipsaci* (Kuhn.) Bastian and on the occurrence of biologic strains. *Ann. appl. Biol.*, XII, 219.
- HURST, R. H. and TRIFFITT, M. J. (1935). Experiments on control of "potato-sickness" by the addition of certain chemicals to soil infested with *H. schachtii*. *J. Helminth.*, XII, 191.
- HURST, R. H. and TRIFFITT, M. J. (1935). Calcium cyanide and other artificial fertilizers in the treatment of soil infected with *H. schachtii*. *J. Helminth.*, XIII, 201.
- HURST, R. H. and TRIFFITT, M. J. (1937). Further experiments in chemical treatment of soil infected with *H. schachtii*. *J. Helminth.*, XV, 1.
- HURST, R. H. and FRANKLIN, M. T. (1937). Field experiments in Lincolnshire on the chemical treatment of soil infected with *H. schachtii*. *J. Helminth.*, XV, 9.
- JOHNSON, L. R. and THOMPSON, H. W. (1936). Tomato sickness in Yorkshire. *J. Min. Agric.*, XLIII, 48.
- JONES, F. G. W. (1945). Soil populations of beet eelworm (*H. schachtii* Schm.) in relation to cropping. *Ann. appl. Biol.*, XXXII, 351.
- LEIPER, R. T. (1940). The potato eelworm problem of to-day. *J. Roy. Agric. Soc. Eng. C*, Part III.
- MAC M., M. (1932). "Potato-sickness" and the eelworm *H. schachtii*. *Imp. Bur. Agric. Parasitology, Notes and Memoranda*, No. 6.
- MILES, H. W. and TURNER, W. H. (1929). On the control of the root knot eelworm, *H. radicum* Mull. *J. Helminth.*, VI, 59.
- MILES, H. W. (1930). Field studies of *H. schachtii* in relation to potato-sickness. *J. Helminth.*, VIII, 103.
- MILES, H. W. and MILES, M. (1942). Investigations on potato root eelworm, *H. rostochiensis* Woll. *Ann. appl. Biol.*, XXIX, 109.
- MILES, H. W., HENDERSON, V. E., and MILES, M. (1943). Field studies of potato root eelworm *H. rostochiensis* Woll. *Ann. appl. Biol.*, XXX, 151.
- MINISTRY OF AGRICULTURE AND FISHERIES (1930—1945). *Monthly summary of insect and allied pests occurring in England and Wales*. (Private Circulation).
- MORGAN, D. O. (1925). Investigations on eelworms in potatoes in South Lincolnshire. *J. Helminth.*, III, 185.
- PETHERBRIDGE, F. R., STAPLEY, J. H., and THOMAS, I. (1938). The beet eelworm (*H. schachtii* Schmidt). *J. Min. Agric.*, XLV, 226.
- POWELL, A. K. (1939). Investigations upon the pea strain of *H. schachtii* Schmidt and its role in the causation of pea sickness. *Ann. appl. Biol.*, XXVI, 572.
- SMEDLEY, E. M. (1938). Experiments to determine the relative toxicity of ammonium chloroacetate and related chemicals to potato eelworm. *J. Helminth.*, XVI, 177.
- SMEDLEY, E. M. (1939). Experiments on the use of isothiocyanates in the control of the potato strain of *H. schachtii* Schmidt. *J. Helminth.*, XVII, 31.
- STANILAND, L. N. (1945). Occurrence of *Anguillulina dipsaci* Kuhn. on weed hosts. *Ann. appl. Biol.*, XXXII, 171.
- TRIFFITT, M. J. (1929). Preliminary researches on mustard as a factor inhibiting cyst formation in *H. schachtii*. *J. Helminth.*, VII, 81.
- TRIFFITT, M. J. (1930). On bionomics of *H. schachtii* on potatoes with special reference to the influence of mustard on the escape of larvae from cysts. *J. Helminth.*, VIII, 19.
- TRIFFITT, M. J. (1934). Experiments with the root secretions of grasses as a possible means of eliminating *H. schachtii* from infected soil. *J. Helminth.*, XII, 1.
- WALTON, C. L., OGILVIE, L. and MULLIGAN (1933). Observations on the pea strain of the eelworm, *H. schachtii* and its relation to "pea sickness." *Ann. Rept. Long Ashton Station*, 74.

OBSERVATIONS ON THE SPECIES OF FLEA BEETLES INFESTING BRASSICA CROPS IN THE WEST OF ENGLAND.

By MAY J. HADDOCK.

During the seasons 1944 and 1945 when experiments on the control of flea beetles (2) were carried out in the Western Province, flea beetles were collected and an analysis has now been made of the species taken in the five counties of the province.

Of a total of more than 3,000 specimens examined, 98% belonged to the genus *Phyllotreta* Foudr., whilst the remainder consisted of *Chaetocnema concinna* Marsh., a few examples of *Longitarsus* spp. and a single example of the genus *Aphthona*.

Table I shows the percentages of the species of *Phyllotreta* most commonly taken in the five counties in both years.

TABLE I.

				Glos.	Herefd.	Som.	Wilts.	Worcs.
<i>P. undulata</i> Kuts. . . .	1944			59	70	30	9	37
	1945			60	25	39	13	44
<i>P. nemorum</i> L. . . .	1944			10	2	4	14	5
	1945			6	37	—	27	5
* <i>P. atra</i> Payk. } . . .	1944			24	20	24	55	48
<i>P. diademata</i> Foud. } . . .	1945			32	29	31	29	47
<i>P. cruciferae</i> Goetz. . . .	1944			2	1	30	1	2
	1945			—	—	30	6	—
Other species	1944			4	8	13	2	9
	1945			2	10	—	6	5

* *P. atra* and *P. diademata* are bracketed since it is difficult to distinguish between the females of these species without dissection, and it was decided not to give separate figures for the males as the sex ratio differed considerably at the various centres.

P. undulata and the two black species, *P. atra* and *P. diademata*, were abundant throughout the province, the former being the most common except in Wilts. and Worcs. In Wilts. the black species were predominant, whereas in Worcs., *P. undulata* and the black species were present in approximately equal numbers and formed 37–48% of the total beetles examined from the county. The numbers of *P. nemorum* were usually small, but in Wilts. this species was quite as common as *P. undulata* (13 to 27%), and in 1945 in Hereford it was abundant (36.5%). Somerset was exceptional in that 30% of the flea beetles taken consisted of *P. cruciferae*, a species which was not common elsewhere in the province.

On the whole there was a close agreement between the figures for these five species for the two years. The fact that a fluctuation of as much as 30% occurred in the numbers of *P. nemorum* in Hereford suggests that the various species respond differently to local environmental conditions such as temperature, wind, number and type of weeds and tilth. It should be emphasised that in attempting to control "turnip fly" the farmer has to deal, not with

a single species, but with a whole complex of related species differing in many features such as winter-hardiness, choice of hibernating sites and host-plant preference. The influence of the latter is shown in Table II, which gives the populations of the five common *Phyllotreta* spp. in relation to various crops.

TABLE II.

				Kale	Cabbage	Turnips*	Radish†	Kohlrabi‡
<i>P. undulata</i>	..	..	1944	39	22	18	22	—
			1945	45	12	23	—	31
<i>P. nemorum</i>	..	..	1944	5	1	14	—	—
			1945	11	36	6	—	37
<i>P. atra</i> <i>P. diademata</i> }	..	..	1944	37	30	55	29	—
			1945	34	29	34	—	27
<i>P. cruciferae</i>	..	..	1944	10	31	1	—	—
			1945	7	8	3	—	—
Other species	..	..	1944	9	16	12	50	—
			1945	4	15	35	—	6

* Rape and turnips in 1944 in Wilts.

† A single crop in Wores.

‡ A single crop in Herefd.

P. atra and *P. diademata* were plentiful on all the crops grown in the experiments and formed about 30% of the populations except in Wilts, in 1944, when these species exceeded 50% of the flea beetle population on turnips. On cabbage, turnips and radish the percentage of *P. undulata* was rather lower than that of the black species (about 20%). *P. undulata* and the black species were equally common (about 30%) on kohlrabi, with *P. nemorum* making up the remainder of the population (37%). The crop carrying the highest proportion of *P. undulata* (39–45%) was kale. As stated above, *P. nemorum* was only common in 1945 in Wilts. and Hereford. The highest percentage of this species was 36%, and this figure was reached on both cabbage and kohlrabi, but *P. nemorum* did not exceed 15% of the flea beetle population of any other crop. In both seasons *P. cruciferae* was more common on cabbage than on kale or turnips and this species was not taken on either radish or kohlrabi.

It appears, therefore, that of the five species most common in the Western Province, *P. atra* and *P. diademata* are the most tolerant as regards host crops; that *P. undulata* has a slight preference for kale and that *P. nemorum* and *P. cruciferae* prefer cabbage, but *P. nemorum* will also feed readily on kohlrabi. Since the figures for radish and kohlrabi relate to single crops they may not be representative.

The collections of flea beetles were made during the months April to July, and Table III shows how the percentages of the five common species of *Phyllotreta* varied during that period.

The proportion of *P. undulata* was only 20% of the total collection for April in both years and rose to 35% in May, whereas the numbers of *P. atra* and *P. diademata* remained fairly constant throughout the collecting period. In July 1944 the proportion of *P. undulata* rose with the emergence of the new generations to 64%, but in 1945 there was a fall in the numbers of this species from 35% in May to 22% in June, and the July increase was less marked

than in 1944, reaching only 45%. This may have been due to unfavourable weather at the time when mating and oviposition were taking place, for May and June in 1945 were cool and windy with frequent showers.

TABLE III.

					April	May	June	July
<i>P. undulata</i>	..	..	..	1944	22	35	35	64
				1945	19	35	28	45
<i>P. nemorum</i>	..	..	..	1944	6	5	6	2
				1945	17	20	9	13
<i>P. atra</i>	}	..	..	1944	39	36	46	32
<i>P. diademata</i>		..	..	1945	28	32	34	38
<i>P. cruciferae</i>	..	..	..	1944	10	17	8	—
				1945	18	3	3	3
Other species	..	..	..	1944	23	9	6	2
				1945	19	10	33	3

In 1944 the percentage of *P. nemorum* in the population remained at about 6 from April until July, when it fell to 2%. This fall appeared to be the result of the dying out of the overwintered generation of adults before the new generation emerged, whilst the numbers of *P. undulata* had already increased. The decrease in percentage of *P. nemorum* began earlier in 1945 than in 1944.

This is in agreement with the observations of Newton (1), who states that the emergence of the new generation of *P. undulata* takes place a little earlier than that of *P. nemorum*.

Newton also states that the new generation of the black species, *P. atra* and *P. diademata*, emerge later than those of *P. nemorum*. In the Western Province no increase in numbers of the black species had taken place by the end of July, but, as with *P. nemorum* in July 1944 there was a small decrease from 45 to 32%, as the overwintered adults were dying off.

The habits of *P. cruciferae*, as described by Newton, are similar to those of *P. atra*, but in the Western Province, whilst the percentage of the black species remained nearly constant throughout the period of observations, that of *P. cruciferae* rose to 16.5% in May, then fell to 8% in June 1944, and in 1945 the percentage fell from 17.5 in April to 3.5% in May and remained at this low figure for the rest of the summer.

Of the other species of *Phyllotreta* taken during the experiments the most common were *P. vittula* Redt., *P. consobrina* Curt., *P. nigripes* F., and *P. nodicornis* Marsh.

P. vittula is exceptional amongst flea beetles in that it is known to attack not only crucifers but also cereals. There is, however, some doubt as to when oviposition takes place and whether the insects breed on both host plants.

In the Western Province the proportion of *P. vittula* in the collections varied from 1.0% to 6.5%. This species was found on kale, cabbage and turnips. The highest percentage (6.5) was recorded for Wilts. in 1945 when 22% of the flea beetle population from turnips consisted of *P. vittula*. The turnips were sown in early June and adjoined a crop of spring sown barley, so that it is possible that the adults of *P. vittula* may have migrated from the barley to the turnips.

According to Newton, *P. nigripes* F. emerges early in the season from its hibernating quarters and feeds for a time on a variety of host plants and migrates to rape and turnips later in the year. This was confirmed in the Western Province. Wilts. was the only county of the province where collections were made from rape and turnips. Approximately 10% of the flea beetle population of this crop consisted of *P. nigripes* in both years. In Glos., Som. and Worcs., on kale and cabbage it never exceeded 1.5% of the populations.

P. consobrina Curt., like *P. cruciferae*, was found to be plentiful only in Somerset, where it formed 7.5% of the population in 1944, and it was present in small numbers (less than 3%) in Glos., Hereford and Worcs. It was taken from both kale and cabbage and its greater abundance in Somerset was not associated with any particular host plant.

P. nodicornis Marsh. was found in Wilts. where it occurred at the same site in both years and in each year was about 2% of the flea beetle population.

P. nigripes and *P. consobrina* have been thought to leave their winter quarters earlier than other species of *Phyllotreta* and to complete oviposition and die late in May or early in June, whilst the overwintered adults of *P. undulata*, *P. nemorum*, *P. atra*, *P. diademata* and *P. cruciferae*, do not die until later in the year. This receives some support from observations in the Western Province, where only a few isolated specimens of *P. consobrina* were taken after the middle of May, with the greatest numbers occurring from mid-April to early May. The maximum numbers of *P. nigripes* were also found about the second week in May, after which time only very small numbers were taken until the emergence of the new generation late in June.

Summary.

The "Turnip Fly" or "Turnip Flea-beetle" is not a single species but a complex of species and often five and sometimes eight species may be involved in attacks on brassica crops. The species most commonly occurring in the West of England in the years 1944 and 1945 were the two black species *Phyllotreta atra* and *P. diademata* and the striped species *P. undulata*. Locally *P. nemorum* and *P. cruciferae* were also plentiful.

Brassica seedlings may be infested at any time from April to July, and throughout this period the common species are likely to be the most numerous species of flea beetle on seed beds and in young crops. The common species show little preference for any particular crop and appear to infest kale, cabbage and other farm brassicas with equal readiness. Amongst market garden crops radish and kohlrabi were also found to be infested by a range of species of flea-beetles. Many of Newton's observations on the habits and seasonal occurrence of the species of flea beetles infesting brassicas have been confirmed in the Western Province.

Acknowledgments.

Thanks are due to Mr. H. C. F. Newton, of Harper Adams Agricultural College, for providing named collections of flea beetles from brassicas. Members of the Provincial Advisory Staff, who have made collections for study purposes, include Miss E. L. Britton, Miss C. M. G. Duthoit, Dr. A. J. Lloyd, Mr. F. Raw and Mr. J. Mayor, and the work has been done under the general supervision of Dr. H. W. Miles, Provincial Adviser in Agricultural Entomology.

REFERENCES.

- (1) NEWTON, H. C. F. *Journal S.E. Agric. Coll., Wye, Kent*, 1928, p. 90.
- (2) MILES, H. W. (1944). *Long Ashton Annual Report*, p. 145.

THE PRODUCTION OF CIDER FRUIT ON BUSH TREES.

VINTAGE QUALITY TRIALS.

PROGRESS REPORT No. 2. 1943 CROPS.

By B. T. P. BARKER and L. F. BURROUGHS.

The Annual Report of the Station for 1943 contained the first of a proposed series of progress reports dealing with the vintage quality trials on the crops of fruit produced at the trial centres where the production of cider apples on trees grown in bush form is under investigation.

In that initial progress report the objects of the trials were stated and the methods of testing vintage quality selected for the purpose in the first instance were described. The results obtained from the samples of fruit of the 1942 crops available for the tests were reviewed in some detail and it was shown that certain general conclusions applied to the ciders made from those samples. It was evident, for instance, that the respective trial centres impressed what was defined as a "locality influence" on vintage quality for all the varieties tested, although the individual varieties maintained their distinctive "varietal" vintage characters. No clear-cut "rootstock" influence on vintage quality of a general character could be discerned, although it was demonstrated beyond question that cider fruit from bush trees on both crab stocks and vegetatively propagated root stocks of the "Paradise" class could yield ciders of high vintage quality when grown under suitable conditions.

Materials and Methods.

Similar vintage trials were carried out with the available samples of fruit of the 1943 crop. The main variation in procedure introduced was the filtration of all the ciders through a Seitz filter immediately prior to bottling, the samples being bottled direct from the filter. This course was adopted in an attempt to avoid as far as possible the complications experienced with the previous season's samples as a result of outbreaks of secondary bacterial fermentations in many cases. The attempt did not prove wholly successful; but some improvement was apparently secured, since the onset of such fermentations occurred later in the life of the affected ciders and the actual number was fewer. A more positive claim is not possible, as the incidence of these disorders varies from season to season.

More elaborate and detailed notes on the individual ciders were made at each of the three samplings than in the 1942-43 trials, since the adequacy of the present methods of assessing vintage quality is also under trial during these early stages of the investigations, as pointed out in the 1943 Report. For the time being these methods cannot be extended or made materially more complex owing to the limited staff available.

One new feature in the observations made on these ciders calling for separate mention concerned their individual degrees of stability. Attention was called to this point by a chance observation of certain differences in behaviour of the ciders after standing for a few days in the opened and partially emptied bottles subsequent to the first sampling of the season in April. Details

of the results are not included in this article, but will be found in a subsequent paper in this Annual Report entitled "Some Observations on the Stability of Ciders," where the subject is considered from a broader point of view.

Results.

The general failure of the 1943 cider apple crop unfortunately extended to those of the bush plots concerned in these investigations. Consequently it was not possible to obtain samples of fruit from some of the trial plots included in the previous season's tests, nor in the remaining cases was material available of all varieties. It was possible, however, to obtain some samples from one centre, Hereford, not represented in those tests and, in addition, samples of a few varieties not cropping in 1942 were secured from some of the centres contributing to the tests of that year. To some extent discontinuity of this kind must be expected during the course of these trials, as well as that due to difficulties of harvesting by members of the Station's staff at trial centres so widely dispersed and with a large number of individual varieties ripening at different periods of the harvesting season. Such irregularity in the tests from year to year is inevitable and incidental to the nature of a long term investigation of this kind.

Considerations of space make it impossible for the detailed results of the analyses of the respective juices and the characters of the individual ciders made therefrom to be included here. They are, however, available for reference at the Research Station by anyone interested. The following results are therefore presented in summarised form designed to show the main features of interest exhibited by the juice analyses and the nature of the ciders yielded by the individual varieties obtained from the trial centres. On this occasion five of the trial centres were represented, these being Long Ashton, Compton Greenfield, Faversham, Hereford and Poundisford.

The following review of the features of interest presented by the ciders made from the 1943 samples of fruit proceeds along similar lines to that given on the 1942 samples. Many of the finer points at issue cannot be settled until the results of the tests over a number of years are available, but it is interesting to note that some at least of the generalisations suggested by the 1942 results have been confirmed. This applies particularly to the characteristic influence of individual centres on the product.

In general, the quality of the individual ciders was good and typical of the particular class to which the variety concerned belongs. There is no reason to qualify the conclusion drawn from the previous results that fruit of good vintage quality can be produced by bush fruit grown under the conditions of these trials.

Juice Composition.

Total Solids and Sugars. The specific gravities of the juices from the respective centres were higher in nearly all cases than those of the corresponding juices from the 1942 crop—in several instances very markedly higher. This year the Poundisford juices were not outstandingly high as compared with those from other centres. On the other hand those from Faversham, which last year were the lowest except in one instance, were on this occasion decidedly higher all round except in the case of the Yarlinton Mill variety, while in one instance—*Medaille d'Or* on the crab rootstock—the abnormal gravity of 1092 was recorded. The samples from the Long Ashton and Compton Greenfield centres also showed definite gravity increases on the 1942 crop figures.

The only sample with a lower gravity than in 1942 was that of Reine des Pommes from the Poundisford centre, the 1943 juice registering 1061 and the two samples of the previous season 1081 and 1070 respectively ; both of the latter, however, were unusually high for this individual variety.

Acidity. Under this trial both the titratable acidity and pH results have been considered, as in the Report on the 1942 samples. In the latter no close correlation between the results of those two methods of expressing acidity could be detected and sometimes the divergence was very wide. The same generalisation can be applied to the 1943 figures, taken by themselves ; but, when taken in conjunction with those of the previous year, signs of correlation begin to appear. For example, only one out of eighteen comparable juices gave a lower titratable acidity in 1943 than in 1942—in that single case the drop was very slight—while sixteen of the 1943 juices gave higher figures. The pH figures showed a reversed picture, as might be expected theoretically, only three of the eighteen cases failing to give a lower pH. Further, the juices of those varieties which gave unexpectedly low pH values in 1942 again gave values below expectation, suggesting that some special varietal character may be operating. There is evidently a need for an investigation on pH values in apple juice and the factors influencing them before the results for acidity now being obtained in these trials can be properly interpreted. Such an investigation lies outside the immediate scope of the trials and would have a much wider significance.

Summarising the results of the titratable acidities for the 1943 trials, it may be stated that they conform more nearly to the normal figures for the varieties concerned than those of 1942, which were low on the whole and abnormally so in some cases.

Tannins. Fifty per cent. of the 1943 samples gave results for tannin content approximately the same as those obtained in the 1942 trials ; the remaining fifty per cent. showed either definite increases or decreases, the number in each direction being practically equal. Thus no comparative generalisation on seasonal influence between those two years can be drawn, although from the point of view of flavour the " tannin " character stood out relatively prominently in the 1943 samples. The Poundisford samples as a group again give higher figures than the other centres, all of which showed about the same levels for the respective individual varieties.

Ash. As was the case in 1942, the total percentage weight of ash present in the respective juices differed rather widely, the extreme limits being 0.1504 and 0.2947. With the general increase in the specific gravities of the juices it was not unexpected to find also a majority of the 1943 ciders showing an increase in ash content. The increase was not quite so general as with the gravities, but the proportion of juices with a larger ash content was sufficiently marked to suggest quite definitely that there is at least a tendency towards a correlation between those two features.

Of the three centres supplying comparable samples for the two seasons' trials, Long Ashton tended to yield the highest ash figures for 1943, with Poundisford and Faversham following in that order.

Ash alkalinity, so far as the order of the centres for the respective varieties is concerned, followed the same course as the total ash, although the actual ratio total ash/ash alkalinity was not invariably closely constant for individual samples.

Total Combined Nitrogen. The significance of the juice content under this heading, especially in relation to vintage quality and rate of fermentation,

was discussed in some detail in the 1943 Report, where it was shown also that the results for the first series of trials presented clear-cut and interesting correlations in respect of "varietal" and "locality influence" effects. The samples available for the tests now under consideration were not sufficiently numerous to permit of much comparison on "locality influence," although, in the limited scope possible, results in line with those for 1942 were obtained; the "varietal" effects, with a wider range of data available, were again clearly marked in conformity with those reported previously.

Regarding the varieties tested on both occasions, Sweet Alford, Yarlington Mill, Chisel Jersey, Tardive Forestier, Reine des Pommes and Dabinett repeat their claim to inclusion in the "low to medium nitrogen" group. Three other varieties, Ellis Bitter, Medaille d'Or and Kingston Black, also included in that group by the 1942 results, were represented in the 1943 trials by single samples only and those were produced from a centre, Faversham, which in the previous year was definitely in the "high nitrogen" class. Thus, although the figures for these varieties on this occasion are approximately of a medium position, they are, taking into account the producing centre, still entitled to retain this place in the "low to medium nitrogen" group.

Of the varieties classed in 1942 as "high to medium nitrogen" only two, Broadleaf Norrnan and Pertheyre, were obtainable for the 1943 trials. The former variety was represented by one sample from the Compton Greenfield centre, graded as "intermediate" for nitrogen content on the basis of the first set of trials, and two samples from the Faversham centre. Two samples of Pertheyres were secured, both from Faversham. The results for all these samples confirmed the position of the varieties in question in the "medium to high nitrogen" class.

The "nitrogen content" figures for 1943 did not present the abnormally wide extreme limits achieved in 1942, the range on the present instance being from 0.0041 per cent. to 0.032 per cent. It should, however, be mentioned that no samples were available in 1943 from Much Marcle, the most pronounced "high nitrogen" centre in the earlier year. The centres from which it was derived in both years—Poundisford, Long Ashton, Compton Greenfield and Faversham—retained their relative 1942 positions as regards nitrogen status, Poundisford yielding the lowest figures. No general marked inclination towards either higher or lower levels in 1943 for individual varieties or centres was revealed, the changes from the 1942 figures being comparatively minor, except in the two Sweet Alford samples from Faversham, which showed a relatively substantial reduction.

Rate of Fermentation. The rates of fermentation of the 1943 juices were obtained under more satisfactory conditions than in the previous year, when bacterial fermentations caused considerable complications. Consequently, it has been possible to obtain a series of figures which show very clear direct correlations with the "nitrogen" content of the individual juices. Such correlations are not absolutely exact—this could not be expected, for the reasons stated in the 1943 Report—but they are sufficiently close to justify a statement that the nitrogen content furnishes a near guide to the rate of fermentation, provided that abnormal types of fermentation do not intervene.

It follows from the above that the comparative characteristics of the 1943 juices of individual varieties and of the respective trial centres referred to in the previous section on "Total Nitrogen Content" are reflected similarly in general in the 1943 rates of fermentation.

Cider Tests.

In all, 44 samples of cider were made in the course of the season's work. They included 11 produced from varieties not available the previous year; these fresh varieties, beginning with Sherrington Norman, are described below after those which were also represented in the 1942 trials have been dealt with.

Pertheyre. Samples from Faversham (2). The two ciders, from fruit grown on Malling I and crab rootstocks respectively, were very similar in general character and composition. They were of the mild bittersweet order and typical of the variety. The juice analyses were remarkably close and high nitrogen content in both cases was associated with rapid fermentation, although that for the "crab rootstock" sample was considerably the faster of the two in spite of an appreciably lower "nitrogen" content. While fairly full in flavour on the palate in the initial stages, the aftertaste was thin.

This variety was not obtainable from the Faversham centre in 1942, but the 1943 samples demonstrate that the general varietal characteristics are reproduced there as clearly as at the three centres represented by samples in the earlier year.

Broadleaf Norman. Samples from Compton Greenfield (1) and Faversham (2). Each of the three ciders was of a pleasant mild bittersweet type, the Faversham samples in particular closely resembling the two Pertheyres just described. The Compton Greenfield sample was the best of the three, being rather more attractive in flavour and aroma, softer and fuller, and the bitter-sweet feature less obtrusive. The acidity was materially lower, as were the nitrogen content and rate of fermentation. This sample was very close in general character to the two samples from the same centre a year earlier, but of rather higher standard. All were characteristic of the variety, which still remains so nearly identical with Pertheyre in vintage as well as tree and fruit characters that the existing names may well prove to be synonyms.

Sweet Alford. Samples from Long Ashton (2) and Faversham (2). The two Long Ashton samples were just distinguishable from the Faversham products by their appreciable astringency and briskness and a lack of the softness associated with the latter. Those features, perceptible also in the Faversham sample of the previous year, were rather more marked than is usual in typical Sweet Alford ciders, although all of the samples were definitely "Sweet Alford" in the general character and pleasant nature of the ciders. The Faversham samples were particularly attractive and fruity in their earlier life in bottle and were superior to the 1942 products.

Ellis Bitter. Sample from Faversham (1). This cider of the mild bitter-sweet class was of medium body, good intensity of flavour, very pleasant and soft as a drink, with some briskness and mild astringency. It was very similar to the corresponding 1942 cider from this centre.

Kingston Black. Sample from Faversham (1). A fair cider of the bitter-sharp class with medium body and softness, some briskness and medium astringency and an appreciable "cheesy" background in its flavour. Not a typical "Kingston Black." Neither the 1942 nor the 1943 samples of this variety have produced a cider that could be identified as a "Kingston Black."

Yarlington Mill. Samples from Faversham (2), Poundisford (1) and Hereford (1). The Faversham and Poundisford ciders were of the mild bitter-sharp class and, as such, too brisk in flavour to be entirely typical of the variety, although their agreeable quality and well-balanced flavour rendered them very pleasant single-variety drinks; that from Poundisford was the fuller-bodied and heavier, the Faversham specimens being lighter and harder

on the palate. They differed considerably from the corresponding 1942 samples and were much superior. The Hereford sample was particularly interesting, coming from a new centre with pronounced "locality influence" features. It yielded a bittersweet cider, full-bodied and with decided softness, which was masked to a large extent by the decided astringency. The nitrogen content of the juice and the rate of fermentation were considerably lower than for the other two centres. Its cider was a typical "Yarlington Mill."

Medaille d'Or. Samples from Faversham (2) and Hereford (1). The two Faversham samples were true medium bittersweet types with rather more than the average tannin for that class. In flavour, however, that feature was not pronounced in respect of astringency, although marked as regards bitterness without harshness. They also showed some degree of briskness and were very full-bodied and rich. They were distinctly better in quality than in 1942.

The Hereford sample was a strongly pronounced full bittersweet, with astringency marked and bitterness intense. The fruity character was well developed, but the body was less full than would be expected from the juice analysis results. There was a definite briskness in the aftertaste. It was a good cider, notwithstanding a high nitrogen content and rapid fermentation of the juice. The ash and tannin contents were the highest recorded for the season. In general respects it was typical for the *Medaille d'Or* variety as grown in this country, whereas the Faversham samples hardly conveyed the impression of the normal high tannin content.

Reine des Pommes. Samples from Faversham (2), Poundisford (1) and Hereford (1). Throughout all the samples the same general varietal characters were pronounced, these being typical of a full bittersweet with some associated aftertaste briskness. The Poundisford cider was full-bodied, soft, with the high tannin content apparent in the astringent rather than the bitter form; slow fermenting and with low nitrogen content, it represented the high-coloured, heavy, fairly fruity, but rather dead "Somerset" full bittersweet type which this centre seems capable of producing naturally. Those from the other centres were much lighter in general character, although the Faversham cider produced by the Malling I rootstock was relatively rich and full-flavoured; its astringency and bitterness were quite marked, but well balanced, and a very soft pleasant drink resulted in spite of a very high nitrogen content and fermentation rate. The other Faversham sample—from the crab rootstock—while showing also the marked astringency, carried the other characters in a lower degree and was of somewhat lower standard notwithstanding rather lower nitrogen and a slower fermentation. In both these ciders the colour was considerably paler than that of the Poundisford sample. The Hereford sample, with the highest juice specific gravity, titratable acidity, tannin and ash content of the whole group, was intermediate in body between the two Faversham samples, but brisker than any and only slightly less dark in colour than the Poundisford cider; a pleasant fruity character was a feature of both its aroma and flavour; in nitrogen content and rate of fermentation it ranked between the Poundisford product and those from Faversham.

Dabinett. Samples from Long Ashton (3), Faversham (2) and Poundisford (1). In every instance these ciders were characteristically medium bittersweets and of Dabinett type. All showed good body, most pronounced in the Poundisford sample and least in the Long Ashton samples. For nitrogen content and rate of fermentation the order was changed by the Poundisford cider occupying the lowest position. In ash content and titratable acidity the Long Ashton ciders were appreciably higher than the others, which were ap-

proximately level for both constituents. All showed a clear briskness in the aftertaste. The general flavour was pleasant, but rather harder in the Long Ashton samples than in the others, of which the Poundisford specimen was distinctly the softest. The Faversham cider from the Malling I rootstock was conspicuous by its persistent bitter aftertaste.

Compared with the corresponding ciders of the previous year there was no striking change in juice composition or vintage character shown by the Poundisford and Faversham representatives. Satisfactory comparison for those from the Long Ashton centre cannot be made for the ciders themselves owing to the prevalence of bacterial fermentation in the earlier year's samples; but juice composition showed a marked increase in specific gravity, titratable acidity and ash content and a large drop in pH for the 1943 products.

Chisel Jersey. Samples from Poundisford (1) and Faversham (2). All three ciders were pleasant, soft and full-bodied pronounced bittersweets of very similar character and standard, typical of the variety. Since no Faversham samples were available the previous year, the only comparison possible is with two Poundisford samples of that year. Those were substantially of the same general type, but rather coarser and with a harsher "tannin" character than the 1943 sample; in juice composition an appreciable increase in specific gravity and titratable acidity and a fall in pH for the 1943 sample were the only changes. The Faversham juices were nearly identical in composition and showed only slight variations from the Poundisford 1943 sample, the only point for mention being a higher titratable acidity and lower pH for the latter. It is also noteworthy that for this variety the nitrogen content of the Faversham samples (0.0085 per cent.) was the lowest figure for any variety at that centre in either year; correspondingly, the rate of fermentation was also lowest.

Tardive Forestier. Samples from Poundisford (1) and Faversham (1). Two very similar pronounced bittersweet ciders, rather lacking in body, moderately soft and with marked astringency and bitterness, the latter character however not being harsh. The only appreciable difference was a slightly fuller degree of body in the Poundisford sample. The juice compositions differed by a higher specific gravity, slightly lower titratable acidity and pH, lower ash content and much high nitrogen content and rate of fermentation for the Faversham juice.

Two samples of this variety were obtained from Poundisford in 1942. With the exception of higher tannin content and pH in that year the juice composition did not differ materially from that of the 1943 Poundisford sample. The cider characters were also similar.

Sherrington Norman. Samples from Faversham (2). Produced from fruit grown on (a) Malling I and (b) Crab rootstocks respectively. In general character they were typical medium bittersweets of fair body with little perceptible difference in the two cases, except a somewhat harder and more marked "tannin" bitter character in that from the Malling I rootstock trees.

The juice analyses showed specific gravities of 1067 and 1071, percentage nitrogen contents of 0.006 and 0.010, and ash contents of 0.195 and 0.226 respectively for (a) and (b). The acid and tannin figures were of an order typical of a medium bittersweet variety and almost identical for both.

Silver Cup. Samples from Faversham (2). These ciders (a) and (b), from Malling I and Crab rootstock trees respectively, were of the rather mild bittersweet type and without much body. Pale in colour, they were also on the "hard" side with a definite astringency perceptible in the aftertaste.

The standard of quality was not high in either case, although (b) was the more pleasantly flavoured ; in other respects the two were very similar.

The juice analyses exhibited rather wide variations for specific gravity, (a) 1073 and (b) 1060 ; tannin, (a) 0.27 and (b) 0.20 per cent. ; total nitrogen, (a) 0.010 and (b) 0.015 per cent. ; and ash (a) 0.213 and (b) 0.135 per cent. Rates of fermentation were rapid and nearly equal.

Stoke Red. Samples from Long Ashton (2). These two ciders were made respectively from crops grown on (a) the upper and (b) the lower half of the trial plot, the soil conditions of the two halves being somewhat different. Both in vintage character and juice composition the two samples were nearly identical. The ciders were of the bittersharp type, rather thin in body, and with a hard bitter astringency especially prominent in the aftertaste.

The only outstanding features for note on the juice composition were the low specific gravities (a) 1044 and (b) 1042, and for the Long Ashton centre, the unusually low nitrogen contents (a) 0.004 and (b) 0.005 per cent.

Knotted Kernel. Samples from Long Ashton (2). These two samples (a) and (b) were obtained respectively from the same two plots as the Stoke Red ciders. Like the latter, the juice analyses showed no material quantitative difference between the two samples ; the specific gravities (a) 1053 and (b) 1050 were on the low side for the season and the nitrogen content figures (0.008 per cent. in both cases) confirmed previous knowledge of the variety as a naturally slow fermenting type. Exact comparison of the vintage qualities of the two samples could not be made owing to bacterial fermentation in the cider from the lower half of the plot ; but it could be discerned that both were of the mild bittersweet type, an unusual result for this variety. The sound cider from the upper half of the plot was a very pleasant and fairly soft beverage of medium body and with no obtrusive astringency or "tannin" flavour.

Royal Wilding. One sample from Faversham. A brisk, very mild bittersweet cider, thin in body and with very slight astringency and bitterness in the aftertaste ; quality moderate. The specific gravity of the juice (1051) was comparatively low for the season in relation to samples of other varieties from this centre, while the nitrogen content was on the high side (0.028 per cent.).

Dymock Red. One sample from Poundisford. A medium sharp cider with some astringency ; the apple character was well marked and the general quality pleasant, although without much body. There was a distinct red tint in the colour, which was medium in depth.

The juice analysis showed a fair specific gravity for the season (1055), a high ash content (0.261 per cent.) and a marked discrepancy between the nitrogen content (0.014 per cent., a very high figure for this centre) and the rate of fermentation, which was the lowest recorded for any of the 1943 juices.

Michelin. One sample from Poundisford. A medium bittersweet cider with decided briskness in the aftertaste. It was of fair body, pale in colour, with a dark rose tint discernible, brisk rather than soft, with a moderate degree of astringency and bitterness.

The juice analysis revealed a high specific gravity (1063), but no feature of particular interest other than those indicated by the description of the characters of the cider.

Summary and Conclusions.

In this, the second Progress Report on tests of the vintage quality of the crops obtained in the series of trials in the production of cider fruit on bush

trees, the results of 45 samples of cider made from the 1943 crops of fruit are considered in respect of the juice analysis and vintage quality.

The trial centres represented in these 1943 tests were again five in number, the only change being the absence of samples from Much Marcle and the inclusion of fruit from the Hereford centre. The "locality influence" of this centre was most marked in the accentuation of the "tannin" character, while its juice gravities and ash percentages tended to be high and the nitrogen content on the low side.

The general conclusions drawn in the first Progress Report (1942) were on the whole substantially confirmed and do not appear to require any modification at this stage.

THE PRODUCTION OF CIDER FRUIT ON BUSH TREES.

VINTAGE QUALITY TRIALS.

PROGRESS REPORT NO. 3. 1944 CROPS.

By B. T. P. BARKER and L. F. BURROUGHS.

The first two progress reports on these trials have dealt in some detail with the following points:—(a) the establishment of a suitable technique for assessing and comparing the vintage quality of the individual ciders prepared from the varieties grown at the respective trial centres, and (b) the comparative survey of the results relating to those ciders, both as regards the chemical composition of the individual juices and the organoleptic characters of each cider as shown by actual sampling at three different stages of maturity during the course of approximately a year following the date of bottling.

As regards these points, the third set of trials—those on the 1944 crops—which form the subject of the present progress report, has proved particularly valuable and may be considered as completing the initial phase, during which the general tenor of the results has been sufficiently established to clear the ground for closer investigation of the more complex issues revealed.

A satisfactory technique for these trials has now been evolved. In view of its bearing on investigational work on the problems of cider-making this technique is described elsewhere in this Report as a separate paper.

The fact that the results of the vintage quality trials with the 1944 crop tend to confirm the general conclusions drawn from the work on the 1942 and 1943 crops makes it unnecessary to present an account of the individual 1944 juices and ciders in such detailed form as in the first two progress reports. A somewhat different and more condensed form of treatment has therefore been adopted on this occasion. It consists, firstly, of a review of the main features characteristic of the seasonal influence of 1944 on the vintage quality of the produce of that year and, secondly, of a critical examination of the respective conclusions tentatively indicated in the two previous reports with a view to their substantiation or modification in the light of the additional data now available.

(As mentioned in those reports, full details of the individual juices and ciders prepared during the course of these annual trials are available for reference at the Research Station by anyone interested).

The 1944 Samples.

The apple crop of 1944 as a whole was abundant. Had the necessary staff been available for harvesting the crops, representative samples of nearly every variety at each of the trial centres could have been secured for the first time. It would also have been a particularly good opportunity for taking crop weight and other records—an important feature in this scheme of bush trials on account of its bearing on the economic aspect of this method of cider fruit production: but again, shortage of staff made it impossible. Notwithstanding these unavoidable difficulties 88 samples for vintage tests were obtained from six centres—Long Ashton, Compton Greenfield, Hereford, Much Marcle, Poundisford and Whimble. This was the first occasion on which samples from the last-named centre had been obtained.

The varieties represented by these samples are stated in the following list, those in *italics* making their first appearance in these tests. The names of the trial centres supplying the samples are given in each case, the sign (2) after any name indicating that samples from trees on the crab and Malling 1 rootstocks respectively were included.

<i>Varieties.</i>	<i>Centres.</i>
Broadleaf Norman	Compton Greenfield (2), Poundisford (2), Whimble.
Bulmer's Norman	Compton Greenfield (2), Much Marcle (2), Poundisford (2), Whimble
<i>Cap of Liberty</i>	Much Marcle.
Chisel Jersey	Hereford (2), Poundisford (2).
Dabinett	Hereford (2), Long Ashton, Much Marcle (2), Poundisford (2), Whimble (2).
Dove	Much Marcle (2).
Dymock Red	Compton Greenfield.
Ellis Bitter	Compton Greenfield, Much Marcle (2).
<i>Fair Maid of Devon</i>	Whimble.
Foxwhelp	Compton Greenfield (2), Much Marcle (2).
<i>Frederick</i>	Poundisford.
Kingston Black	Much Marcle (2), Poundisford (2).
Knotted Kernel	Long Ashton.
Medaille d'Or	Hereford, Much Marcle, Poundisford (2), Whimble.
Michelin	Much Marcle, Poundisford.
Pertheyre	Compton Greenfield (2), Much Marcle (2), Poundisford (2).
Reine des Pommes	Much Marcle (2), Poundisford.
Royal Wilding	Much Marcle.
<i>Slack-ma-Girdle</i>	Poundisford.
<i>Star of Devon</i>	Whimble.
Stoke Red	Long Ashton, Much Marcle (2), Poundisford.
Sweet Alford	Compton Greenfield (2), Long Ashton, Much Marcle, Whimble.
Tardive Forestiere	Much Marcle (2), Poundisford.
<i>White Close Pippin</i>	Compton Greenfield (2), Hereford.
<i>White Jersey</i>	Hereford, Much Marcle (2).
<i>White Norman</i>	Much Marcle (2).
Yarlington Mill Jersey	Hereford, Much Marcle, Poundisford (2), Whimble (2).

Seasonal Influence in 1944.

The seasonal influence on the composition of the juices of the 1944 crop as compared with that on the 1942 and 1943 crops has not been so clearly marked in respect of the individual juice constituents as in those years. For example, while the specific gravities of the 1943 crop were with one exception higher than those on 1942, those from the 1944 crop in the comparable cases were frequently higher than those of the 1943 crop, although in the majority of juices they were lower. In relation to the 1942 juices they were generally higher, although lower in several instances.

As regards acidity the results were also irregular in relation to both previous years, although tending as a whole to be lower than in 1943.

The tannin figures on the other hand were mostly on the high side as

compared with the two previous years: but, again, the exceptions were sufficiently numerous to prevent a more positive generalisation.

The total nitrogen content in the case of the Poundisford samples conformed remarkably closely with the characteristic low results for the two previous years for that centre. For the Much Marcle centre, on the other hand, the results as a whole were materially lower than the strikingly high figures of 1942. (No samples were obtained from this centre in 1943.) For the other centres the general trend was towards lower contents than previously: in fact, in only one case was a content of as much as 0.02 per cent. registered, that being a sample of Pertheyre from Compton Greenfield with 0.0203 per cent.

Thus, in general, seasonal influence in 1944 on the chemical constituents clearly revealed itself only in its effect on the nitrogen content of the juices, which was definitely on the low side. The effects in this case were, as would be expected, reflected in comparatively low rates of fermentation and the usual accompaniments of that feature, viz. ciders of relatively fruity character and good body and colour. It does not follow, however, that the higher quality can be attributed entirely to the lower nitrogen content, because the 1944 improvements in cider-making technique in these trials most probably have contributed in some degree to the higher standard.

To what extent the fact that the 1944 crops as a whole were abnormally heavy has influenced the rather indefinite character of the juice composition for that year cannot be estimated very precisely: but it must certainly be regarded as having tended to obscure the results of "seasonal influence" for the year in the more limited sense of that factor. In so far as the "size of crop" effects were concerned, it may be recalled that the potential crop in any one year is closely related both to the cropping results of the year immediately preceding it and the character of the weather conditions during the fruit-bud initiation period of the latter, as shown by Lees (Long Ashton Research Station Annual Report 1926) in the course of his work at this Station on fruit-bud formation in apple trees.

The General Results of the 1942-43-44 Trials Compared.

The general conclusions drawn from the initial set of trials made in the 1942 crop of fruits were summarised in the 1943 Annual Report of this Station as follows:—

1. "Locality influence" at the respective centres has produced distinctive effects on vintage quality. In this respect the centres fall into three groups:—

- (a) Poundisford, characterised by high specific gravities, slow juice fermentation rates, low acid and nitrogen content, high tannin, and full-bodied ciders.
- (b) Much Marcle and Faversham, characterised by quick-fermenting juices of high nitrogen content and relatively low specific gravity.
- (c) Long Ashton and Compton Greenfield, intermediate between (a) and (b) for the characters specified.

2. In general the "locality influence" of the respective centres has been impressed on all varieties tested.

3. Notwithstanding "locality influence" each variety has maintained its "varietal" vintage characters.

4. No clear-cut effects from "rootstock" influence have been apparent.

The results have also demonstrated unmistakably that fruit of good vintage quality can be produced by bush trees grown under the conditions of these trials.

As will be seen in the second Progress Report, which immediately precedes the present one in the year's Annual Report, the results of the 1943 crop trials on the whole substantially confirmed the original conclusions, which were deemed to require no modification at that stage.

Hitherto in these Reports the term "locality influence" has been used to denote the effects of the individual centres. For greater precision the term "centre influence" will now be used in its place.

The 88 samples yielded by the 1944 crops provided a very fair test of the validity of those conclusions, especially as several of them were obtained from a centre (Whimple) not previously represented in the trials: in this instance the "centre influence" was pronounced and quite distinctive from that shown by all the other respective centres except Poundisford, to which it bore a close resemblance in general.

The extent to which the above conclusions have been substantiated or require modification will now be considered individually in the order in which they stand.

Centre Influence.

During the three years over which these trials have extended crop samples from three centres—Compton Greenfield, Long Ashton and Poundisford—have been examined for each of these years. The Faversham (1942 and 1943), Hereford (1943 and 1944) and Much Marcle (1942 and 1944) centres have appeared twice in the trials, the crop years being shown in brackets in each case. The Whimple centre (1944) as already stated, has been included once only.

On each occasion the group of ciders from each individual centre has borne a more or less well-marked vintage character distinctive for the centre concerned, although subject in a minor degree to seasonal effects. This result is entirely in conformity with the experience of practical cidermakers throughout many generations. It can now be regarded as firmly and scientifically established on the basis of strictly comparable tests carried out with standardised raw material obtained from trees of a group of selected varieties, grown in the same nursery, and from which the possibly disturbing factors of rootstock and age of tree influence have been eliminated. The criticism of this conclusion sometimes put forward prior to these trials quite properly on the grounds that varieties grown in the localities concerned were not the same, the rootstocks of the trees not known and the trees themselves frequently of very different ages, does not apply to the present set of trials.

It appears important, however, at this stage of the investigations to stress the point that the "centre" influence on vintage quality cannot at present be expressed very precisely—possibly hardly even approximately—in numerical form based on the chemical composition of the juices and ciders of the individual varieties concerned. The chief reason for this difficulty is that the "centre" factor is only one of many affecting the chemical composition. Weather conditions, for instance, differ widely from season to season and for the individual districts in which the trial centres are located. Also, with the conditions under which these trials are conducted, manurial and other treatments concerned with the management of the individual trial plots are not uniform at every centre. Then, too, while most of the plantations are still being maintained in ungrassed form, the cultivations and intercropping have differed

at the individual centres: in at least one case grassing down has now taken place. Until it becomes possible, if ever, to assess separately the individual effects of such factors. "centre influence"—in the sense used in these Reports—must be expressed along broad and general lines, although in certain directions more or less definite tendencies relating to juice composition appear to be indicated already.

Fortunately, however, the organoleptic characters of the ciders of the individual centres are unquestionably more distinctive and, to the trained palate, recognisable in the average case without much difficulty. For example, a Poundisford centre sample normally is thoroughly typical of the full-bodied and full-flavoured, rich, but somewhat heavy and high-coloured ciders characteristic of the best cider-making areas of Somerset. For the Long Ashton centre the corresponding cider made from the same variety is thinner and harder, as well as being relatively deficient in richness of flavour, general vintage quality and depth of colour. For Compton Greenfield a rather light medium-bodied, fairly soft, pleasant and rather fruity cider of fair colour is characteristic. The Hereford centre is distinguishable for relatively high tannin character, medium body and some tendency to hardness. For the single season's trials with the Whimble samples their characters on the whole have been more positive than usual in a Devon-grown cider, approaching the Poundisford character without the heaviness of the latter, but softer and with rather less marked tannin characters than those of the other centres: in the majority of cases the typical Devon softness was conspicuous and the colour tended to be above average.

The outstanding feature for the Faversham centre has been the full fruity character of the flavour, persistent until the cider begins to mature under the influence of summer temperature: in spite of the relatively high nitrogen content of the freshly expressed juice the flavour and aroma till then have escaped both harshness and hardness, but subsequently deterioration in those respects occurs and the characteristic fruity features disappear, their place being often taken by some unpleasantness in aroma and flavour. This change is usually associated with some after-fermentation resulting from the high nitrogen content. The Much Marcle centre is very similar in those respects, which place these two centres in a class by themselves. The number of comparable ciders from the two centres thus far examined is too small to permit of any generalisation as to possible characteristic differences between them.

Centre Influence in Relation to Variety.

The foregoing notes on the "vintage characters" of the individual centres have been based predominantly on the response of varieties of the bittersweet class. That has been inevitable, since such varieties are considerably more numerous in these trials than those of the sharp and sweet classes: but it seems so far that the bittersweets on the whole tend to show locality influence in a clearer manner and to a greater degree than varieties of the other two classes.

Another feature of varietal response also suggested by the results thus far available is that varieties of either class which have as a varietal character a natural tendency towards a relatively low nitrogen content and slow fermentation rates are more responsive to locality influence than those with more nitrogen and faster fermentation.

Apart from these qualifications no modification of the original conclusions that centre influence is impressed on varieties in general is called for at present.

Here, again, the conclusion supports general experience in cider-making practice.

Retention of Varietal Vintage Character.

The results of the first season's trials have been very definitely confirmed by the subsequent ones. In the forty years' experience of single-variety cider-making tests carried out at Long Ashton with fruit from the usual form of cider orchards it has already been shown very clearly that individual varieties have their own specific vintage character and that, while this varietal character is subject to comparatively wide variation in degree of intensity according to the place of growth and to seasonal influence, it is exceptional to find it unrecognisably diminished.

This experience has been reflected in the present series of trials with fruit from the bush plots. Some varieties undoubtedly have their "varietal" character more strongly marked than others and the most pronounced examples occur among those members of the sharp class which normally have a tannin content entitling them to be described as bittersharps. Into this group fall such well-known and outstanding varieties as Kingston Black, Foxwhelp, Frederick, Cap of Liberty (syn. Red Soldier), Dymock Red and Cowarne Red : to that list it is now evident that the more recent discovery, Stoke Red, can be added. Each of these, except Cowarne Red, is included in the bush trial scheme, and it is noteworthy to find the respective varietal characters already showing up more or less distinctly, in spite of the comparative youth of the trees and the tendency towards the damping-down of those characters due to such immaturity. Kingston Black has been slowest in the development of its typical vintage character ; this may be due in part at least to the fact that also during the three seasons of these vintage trials this apple has failed to produce its usual characteristic high-grade standard of cider made with fruit taken from old-established grass orchards.

Rootstock Influence.

Particular attention has been given to the composition of the juice and the vintage quality of the ciders yielded by the respective samples of fruit from the trees worked on the two test rootstocks, Crab and Malling I. At all centres these two rootstocks are under trial for each variety of apple.

As in the first season's trials, no obvious and definite rootstock influence has been noted subsequently. This statement is not intended to convey that the respective ciders from the two rootstocks have been invariably so nearly similar that it has been difficult to distinguish the one from the other. Frequently that has actually been the case, but at times a material difference in character and chemical composition has been noted. No regular correlation in respect of these differences has been discovered, individual features of difference being shown in reverse order apparently without obvious reason in different pairs of samples.

For purely pomological reasons some definite and consistent "vintage quality" differences might have been expected. The most probable explanation to account for their non-appearance hitherto is that the trees are still in too immature a condition for a rootstock influence to be noticeably and regularly effective.

Vintage Quality as Influenced by the "Bush" form of Culture.

Each season has witnessed a general improvement in the vintage quality of the samples of cider made. This result has been unquestionably not merely

a matter of more favourable seasonal influence, if any. The technique associated with the making of the ciders has been improved in points of detail with corresponding good effects on their general quality.

From the start, however, it has been obvious that ciders of exceptional quality can be produced from some of the samples of fruit and that the results tend in general to represent an improvement in standard when made on the small-scale methods adopted as compared with corresponding tests with similar raw material under the normal large-scale methods utilised in the ciderhouse. Leaving the method of making out of account, it can be stated that it has been conclusively demonstrated that, given varieties of good natural vintage quality, cider fruit of a very high vintage grade can be produced well within ten years from the time of planting in bush plantations such as those concerned in these trials. Furthermore, with suitable varieties, crop yields at the rate of 5 tons per acre and over were obtained in the sixth year following planting.

Thus these results are of very considerable importance from the point of view of the English cider industry and the serious present outlook as regards future supplies of its raw material, provided that a satisfactory solution to certain practical difficulties associated with the cultivation and management of such bush plots can be found and that the economics of the method are sound. A longer duration of these trials is required before definite answers can be given on these matters.

THE DETERMINATION OF VINTAGE QUALITY IN CIDERS.

By B. T. P. BARKER and L. F. BURROUGHS.

Introduction.

The quality of a cider is governed basically by the vintage value of the fruit from which it is made. The maximum potential quality of a cider made from a given lot of fruit is already predetermined the moment the fruit is parted from the tree. How nearly the ultimate result approaches that maximum depends on many other factors—which can be grouped broadly into two classes, (a) management and (b) natural factors—functioning independently of the control of the fruitgrower and cidemaker. Those under (a) are concerned with the management of the fruit subsequent to its removal from the tree and of the processing and other treatments involved from the time of milling and pressing of the fruit until the finished product is on the point of consumption. Those under (b)—leaving out of account for the moment any concerned with the determination of the initial vintage quality of the fruit—include, among others, such factors as (1) the weather conditions prevailing from the time the fruit is taken from the tree until the cider is ultimately consumed and (2) the character of the microbiological flora present on the fruit at the moment of milling. In some degree these can be modified by management operations—for example, temperatures in the ciderhouse could be brought to more appropriate ranges and fermentations dominated by the use of selected yeasts instead of leaving them to the chance naturally-occurring yeasts of the season—but none the less the cidemaker cannot entirely counteract their influence and in general practice rarely attempts to do so.

To get the best possible results from the initial vintage quality of the fruit—so far as management can ensure them—it follows that the cidemaker

should take full control of the fruit at harvesting and throughout the after-care period in the orchard, during transport to the cider factory and in the maturing period there prior to milling. Mostly it is only in the cases of farmer cidermakers and commercial firms owning orchards that this is possible: in general practice most commercial firms do not take over control until the fruit is delivered to the factory and by that time considerable deterioration in vintage quality has usually occurred. Thus, from the purely practical point of view, the statement made above as to predetermination of the vintage quality of the cider may be amended to the effect that the potential maximum quality is predetermined by the state of the fruit at the moment of milling.

From the point of view of the research worker on cider problems, however, it is obvious that many of the latter require that full control should at the latest take effect from the beginning of fruit harvesting: for only thus can he really have any chance of accurately assessing and comparing the true vintage quality of any individual samples of fruit.

The above considerations are a necessary prelude for the proper appreciation of the subject with which this paper is primarily concerned, viz. the nature of the technique required for the satisfactory evaluation of the vintage quality of a given sample of fruit or cider.

Early Investigations on the Vintage Quality of Cider and Perry Varieties of Fruit.

When in 1904 this Institute began its investigations on cider making and its associated problems relatively little definite knowledge on the English-grown raw material of the industry existed.

The Herefordshire Pomona compiled by Hogg and Graves Bull and published 1876—1885 (1) contained the most detailed information up to that date, but it was concerned mainly with the better-known cider apple and perry pear varieties grown in that and the adjacent counties. Useful details of the pomological and orchard characters of the varieties described were given. In addition, the acid and tannin contents and the specific gravity of their respective juices were recorded, but these appear to have been results of analyses of a single sample of juice in each instance and frequently are not in close accord with more recent analyses of the varieties in question. Statements of vintage quality were also made and these seem to have been based largely on local repute—an unreliable guide according to more recent experience.

Between the years 1894 and 1903 many analyses of juices of individual varieties were made by Lloyd (2) in the course of his cider investigations at Butleigh Court on behalf of the Bath and West and Southern Counties Agricultural Society. The details given include specific gravity, reducing and cane sugars, acidity, tannin content, total solids and extractives. This information has proved valuable for reference and is in general concord with more recent analyses. It lacked, however, the results of actual cidermaking trials with those varieties and their vintage value could not be more nearly assessed than the analytical data warranted.

It was evident, therefore, at the start of the work at Long Ashton that the immediate line of investigation of first priority must be that of the vintage and orchard qualities of the varieties then existing in the farm orchards of the cidermaking areas in the West of England. The urgency of such research was all the more pressing on account of the advanced age and often decrepit state of a seriously large proportion of those orchards. Thus the problem to be faced at that time resolved itself at the outset into one of compiling with

the least possible delay a selection of varieties of proved vintage and orchard merit—not less than a minimum of 24 in number and ranging in ripening period from September to January. The selection also required representation of each of the three main classes of vintage varieties—sharp, sweet and bitter-sweet—to cover that ripening period.

To that end a nursery was at once established for the propagation of over 10,000 young standard trees to be used for trial orchard purposes in all the cidermaking districts in this country. The varieties propagated therein in due course were chosen for their vintage promise, so far as could be ascertained from local repute and the results of such actual cidermaking trials as could be completed before the stocks were budded or grafted. From that time until now—with the exception of the war years—propagation for orchard trial has been carried on continuously with additional varieties after their vintage quality tests have justified such trial.

Beyond this brief reference to the purpose and existence of these orchard trials this paper is not concerned with them, its main purpose as already stated being to describe the methods of assaying vintage quality evolved during the course of these investigations.

The Essentials of Vintage Quality Determinations.

For vintage quality trials two distinct, though mutually complementary, sets of data have to be ascertained—(a) the chemical composition of the juice and (b) the characters of the fermented beverage prepared from the sample of fruit under examination. Without (b) the trial is incomplete, because the organoleptic features of the product cannot be analysed by existing chemical methods: without (a) those features do not express with the necessary precision the quantities of the juice constituents determinable by chemical means.

Defects of Previous Methods of Determination.

For both (a) and (b) the methods of determination and expression at the outset of these trials had several weak points, and, in spite of various improvements introduced as the work has proceeded, have remained in some respects inadequate for investigational work calling for a very high degree of accuracy. For example, the analytical data refer only to the major juice constituents: even for them the methods of determination and expression are open to criticism (3). Again, the preparation of the fermented liquor until recently has had to be carried out under ordinary commercial conditions in the cider house, subjected to the drawbacks referred to below associated with relatively large-scale work.

The more urgent specific points of improvement in these directions required for more advanced investigations can be summed up as follows.

For general purposes hitherto, the data determined relating to the chemical composition of the juices under examination were confined to (a) the specific gravity—which gives an approximate measure of the total solids and sugar contents of the juices—(b) the acidity, ascertained by titration with standard alkali solution and expressed in terms of malic acid content per cent. (c) the tannin content, as determined by the permanganate-indigo carmine method—which represents, more strictly speaking, the permanganate-reducing power of the sample when indigo carmine is used as the indicator for the end point of the reaction—and (d) the rate of fermentation, as shown by the average fall in specific gravity in twenty-four hours by a sample incubated at 25°C.—which is roughly a measure of that part of the total nitrogen content of the juice suitable for yeast nutrition. Such data, in fact, furnished information only on

the potential alcoholic content of the liquor if fully fermented, the nature of the acid/tannin ratio, the corresponding character of the flavour of the matured product, and the probable degree of natural sweetness which could be retained in the cider by the use of one or more of the various methods available for arresting fermentation. The finer points of chemical composition and their possible bearing on aroma, flavour, body and general character of the vintage quality in other respects were not ascertained. Under the conditions the work was necessarily conducted the analytical work had to be restricted to the lines mentioned on account of shortage of available staff.

The other essential side of the juice examination, viz., its fermentation and the characters of the fermented product, was carried out under the usual conditions of practical cidermaking. Usually the bulk of liquor under trial was sufficient to yield either a 30-gallon cask or a hogshead of the finished article in addition to two or three dozen screw-stoppered pint bottles taken for sampling purposes and filled direct from the filter after the final filtration. Since it was found by experience that a cider retaining some natural sweetness facilitated the assessment of vintage quality, filtration was generally done at as nearly as possible a specific gravity of 1025. That degree of gravity was not always retained, even approximately, owing to the varying degree of after-fermentation in bottle, dependent primarily on the vintage quality of the individual samples.

Vintage trials carried out under such comparatively large-scale conditions, notwithstanding their greater appeal to the average practical cidemaker, were subject to a number of disadvantages from the research point of view, especially in relation to degree of control and accuracy of the results in general. Among such associated weaknesses the following may be mentioned :—

(a) *Control*. Large-scale operations necessarily incur reliance to a considerable extent for the purely manual work involved on the services of a labour staff which from the nature of the case cannot be expected to possess the technical qualifications essential for the maintenance of the requisite standard degree of care and accuracy in a task extending over most months of the year and entailing considerable variety in the nature of the work to be performed.

The equipment for such work consists of large and cumbersome installations of plant of relatively complex construction and fermentation and storage vessels with their fittings and liquor conduits, all of which are difficult to maintain in that condition of microbiological cleanliness without which the results must be open to criticism.

(b) *Supplies of Raw Material*. With a minimum quantity of 30 gallons of the finished product necessary for a single test under large-scale conditions the equivalent quantity of fruit required is about 5 cwts. Under existing farm orchard conditions that weight of a single variety from comparable trees grown at a given centre is not readily obtainable for the trials in successive years requisite to counterbalance the "seasonal influence" factor. Moreover, a sample of fruit of that weight rarely consists of specimens of a fair degree of uniformity and a large proportion of the individual fruits is likely to be affected more or less by bruises or fruit rots. Thus there is a lack of uniformity in the sample and, also, the standard of cleanliness is uneven.

It follows, also, under these circumstances that control and replicate tests are rarely possible, while an experiment involving several different treatments is practically out of the question unless mixed fruit with all its unsatisfactory accompaniments from a scientific point of view is used. Thus an intensive or elaborate type of investigation is impracticable.

In spite of such weaknesses the methods have been reasonably adequate to meet the primary needs of the initial purposes for which they were used, viz. the examination of individual varieties of cider apples and perry pears to determine their inherent vintage value and the selection of a high-quality group for further propagation.

With the passage of time, however, it was inevitable that the foregoing method of evaluating vintage quality with its obvious defects would prove inadequate for investigations of a more complex order. In particular, improvements in the direction of the use of smaller samples—permitting replicates as required—and more strictly controllable conditions would have to be introduced.

The need for an improved method became urgent when the trial plots concerned with the investigations on the culture of vintage apples grown in bush form (4), reached the cropping stage. In this line of research the point at issue is not a question of the determination of the standard of vintage quality of a given variety of apple, *i.e.* the standard inherent to the variety, but a comparison of different samples of fruit of a single variety grown under different conditions.

In this connection it can be recalled that the vintage quality of a sample of fruit is the result of the conjoint action of many factors, of which the inherent "variety" factor is only one. That, however, is a constant for any specified variety and, as regards its influence on vintage quality, may be considered as equal in degree in its effect on the character of all ciders made from that variety: the only time at which control is exercisable in this case is at the initial choice or selection of the variety. Thus in comparisons of individual samples of a given variety this factor does not affect the issue. It is the other factors concerned—all of which are subject to variation in degree of effect—which are responsible for the differences in quality between the ciders yielded by any single variety. Their combined action in some instances is very pronounced: in other cases the "variety" effect outweighs all other factors.

As mentioned in the Introduction, some of these variable factors are beyond control, although their influence in certain cases can be modified by appropriate management. Besides these uncontrollable factors there remain others directly controllable by suitable treatment or procedure.

At present comparatively little is known as to the precise influence of any of these variable factors on vintage quality. Cider research in general is now at a stage where such knowledge is urgently required before much further progress is possible. Consequently the development of a more refined technique of examination has been the subject of special attention at Long Ashton during the past few years and has led to the evolution of the method described below. It has so far been tested primarily on the samples of fruit obtained from the "bush" cider trial plots and the results obtained represent a great advance on those from the method previously used.

It is in effect the elaboration of a method used at Long Ashton in laboratory trials prior to 1914. At that time it was left relatively crude and incomplete in certain respects, because the type of equipment required was not in production: this applied particularly to apparatus for fermentation control and thus all the ciders made under those conditions had perforce to be allowed to ferment until that process came to a natural end—which normally resulted in a dry cider with no residual natural sugars.

Invaluable as the improved method promises to be for cider research work in general it is not suggested that the larger scale trials under ciderhouse

conditions should be superseded entirely. It is still desirable to demonstrate under the normal practical conditions of ciderhouse work the findings of the laboratory and to ascertain how they can be applied to best advantage in ordinary practice.

Small-scale Cidermaking Technique.

Harvesting and Transport of Fruit. As mentioned in the Introduction, the actual harvesting of the fruit must be done by the research worker himself or competent trained assistants to ensure that the fruit is taken at a suitable stage of ripeness. Unless for special reasons the trial requires fruit gathered from the tree before it has reached its full state of maturity thereon it is preferable for general purposes to defer harvesting until the latter stage is reached, *i.e.* when the individual apples are ready to fall at a touch. The fruit should be hand-picked from the tree, but this cannot always be timed in practice to secure the apples before they have fallen: in the latter case there is no vital objection to the collection of fallen fruit so long as it has fallen recently and care is exercised to exclude bruised or otherwise damaged specimens from the sample collected.

In selecting the sample the individual fruits must be as uniform in general character as possible and representative of the total crop of fruit borne by the tree. Thus the sample should be taken from all parts of the tree and not from the sunny or shady side exclusively: it must also be representative of the average size rather than a group of the larger or smaller fruits.

As collected, the fruit must be carefully handled and placed in the receptacles in which it is to be ultimately stored until ready for milling, whenever this is practicable (see next Section). Otherwise clean sacks should be used.

Transport is best done by car to avoid delay in delivery and minimise bruising damage.

Storage of fruit. The fruit is gathered into the storage boxes in the orchard and conveyed in them to its ultimate destination. The advantages of using boxes rather than sacks are that the fruit is less subject to fungus rots, there is no risk of a "sack" taint and the fruit can be more easily kept under observation.

Preparation for milling. The stored fruit, when judged to be in the proper condition for milling, must be sorted to remove all spoiled and rotten fruit. Hitherto this has been done by hand at the time of milling but, if necessary, a washing device could be used.

Milling and pressing. Milling is carried out in a motor-driven American grater-type mill fitted with a wooden hopper, and a tub to collect the pomace. At the time of milling any unusual features in the appearance and condition of the fruit should be noted. The pomace is transferred in a stainless steel bowl to a hand-operated press and spread by hand on hemp cloths 36 ins. square supported on racks 20 ins. square. Each cloth holds 10–15 lbs. The cheese is pressed at 60 lbs. per square inch on the racks.

The juice, after collection in a stainless steel bucket, is strained into glass jars of $\frac{1}{2}$ gal., 1 gal., $2\frac{1}{4}$ gals. or (occasionally) 5 gals. capacity—most conveniently through a double thickness of butter muslin. At this stage a sample is taken for chemical analysis.

Fermentation. The jars are completely filled with juice and left unstoppered while the early stage of rapid fermentation is proceeding with the extrusion of suspended solid matter in the resulting froth. When this

stage is completed, bungs with glass fermentation locks are fitted. The fermentation is continued at ordinary room temperature and readings of the specific gravity are taken three times a week.

One of the advantages of fermentation in glass vessels is that any unusual feature, such as the formation of a pectic clot, is at once apparent.

It has been noted that, for vessels ranging from $\frac{1}{2}$ pint to $4\frac{1}{2}$ gals. capacity, the smaller the vessel the more rapid the fermentation.

Clarification and Bottling. In view of the need to compare ciders under approximately standard conditions, all are bottled at the same specific gravity.

In trials at Long Ashton from 1942 onwards fermentation was as far as practicable arrested by centrifuging when a gravity of 1025 was reached. In 1942 the ciders were bottled direct from the centrifuge: but this led to so much secondary fermentation in bottle that the character of the ciders was obscured. In 1943-44, therefore, centrifuging was followed by Seitz filtration and filling into sterile bottles. Sterilisation of the bottles and corks was effected with 2% SO_2 solution. The centrifuged ciders were kept in the cold store until a group of 12-18 had accumulated for filtration. This was carried out on a 30 cm. Seitz filter with 4-6 filter pads (No. 2 grade from Messrs. Hodgkinson).

The method of filtering thus described is, however, time-consuming and wasteful of cider, since the filter must be flushed through with at least half a gallon of the cider under treatment to remove all traces of the previous sample. A new method of filtration, using a kieselguhr filter made by the Metafiltration Co., is now under test and will be reported on later.

Critical Sampling of the Ciders.

It was decided that normally the ciders should be sampled on three occasions—late spring, mid-summer and autumn. For purposes of record and comparison from year to year it is necessary that the descriptions should be as detailed and accurate as possible. Where any character lends itself to quantitative expression, it should be so expressed. Notes are made under the following headings and procedure:—

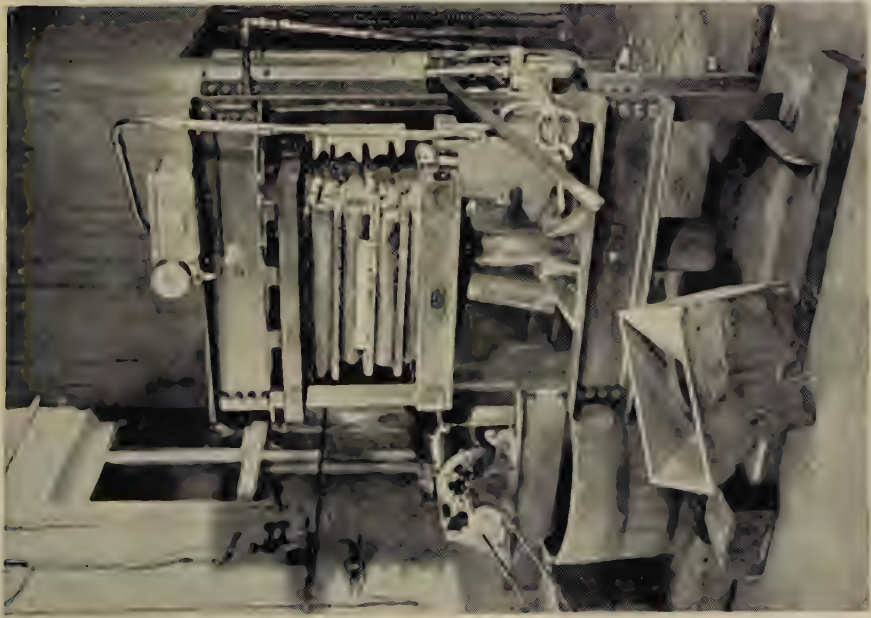
Clarity and Deposit. When taking the bottles from the cellar, the degree of clarity of the cider and the nature and extent of the deposit in each case are noted. The bottles are then brought to the laboratory and allowed to stand at room temperature for 24 hours before opening.

Gas. On opening and pouring into the glass, the amount of gas present is estimated on a purely arbitrary scale of notation ranging from 0 to 5. For finer grading + and — signs are used, 1 + representing rather less gas than 2—. It is not known yet what actual CO_2 content these various levels represent, but the exact chemical estimation is possible and will be made as soon as the opportunity arises.

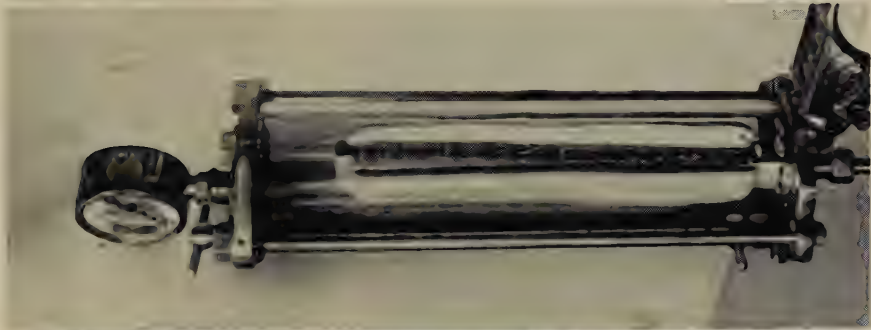
Aroma. The intensity of aroma of the freshly opened is recorded as slight, medium or full, again with a + or — sign where necessary. The character of the aroma is classified as of bittersweet, neutral or sharp type, and other features such as fruitiness and alcohol are noted, when called for.

Flavour. The flavour is described under various headings as follows:—

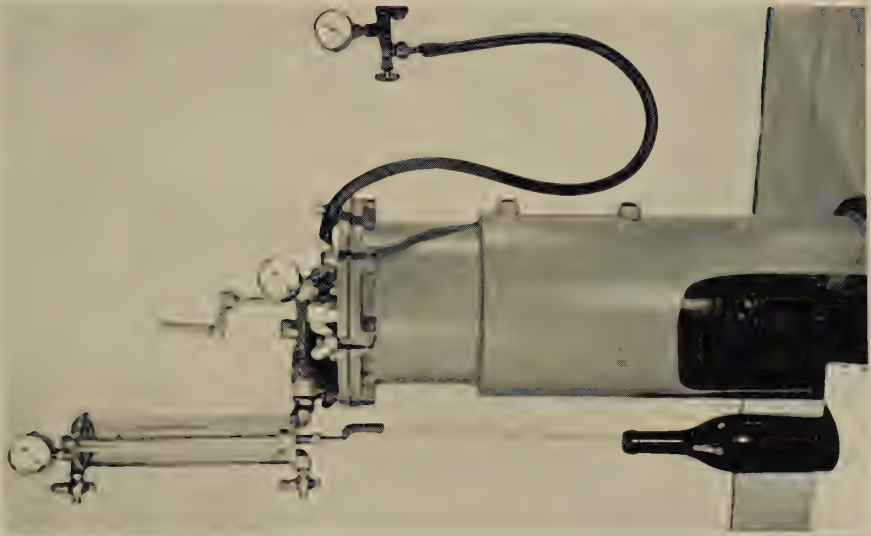
- (a) general class type; *i.e.* sharp, sweet or bittersweet.
- (b) character of tannin and/or acid.



Cider Mill and Hydraulic Press used
for Small-scale Cider-making.



Filter Pack with Central
Core exposed



Filtration Equipment for Small-scale
Cider-making.

- (c) intensity of flavour, other than acid and tannin characters* ; character of flavour.
- (d) body, recorded as thin, medium, or full, with + or — sign where necessary.
- (e) degree of hardness or softness.
- (f) any other pertinent features.
- (g) general comments, summary, and comparisons with other preceding ciders.

Colour. Colour is recorded as pale, medium or full, with a note describing the shade or tint of colour where this is abnormal.

The use of a tintometer and colour standards would lead to greater precision here.

Specific Gravity. The specific gravity at the time of sampling is determined by hydrometer, after degassing the cider by pouring from glass to glass. Since the specific gravity indicates approximately the percentage of sugars present, it affords a fair measure of the degree of sweetness of the cider concerned.

Quantitative Determinations.

Juice Yield. No quantitative work has been done so far on the yields of juice obtained in the Bush Plot Cider Experiments. In 1945, however, a preliminary trial was made to evolve a technique to investigate the relation between the maturity of the fruit and the quality and yield of juice obtained.

The accurate determination of yield presents certain difficulties on the small scale, and the method chosen as perhaps most nearly representing the true yield was as follows. The sample of fruit was weighed in its box and, feeding the mill by hand, the apples unfit for milling were discarded and retained for subsequent weighing in the box ; the pomace after pressing was weighed, and the yield of juice obtained by difference from the weight of fruit milled ; the yield was then calculated in terms of gallons per ton.

The accuracy of the method depends on the precision with which the weight of pomace can be determined. Working with sample of 56 lb. of fruit, an error of $\frac{1}{4}$ lb. in the weight of the pomace represents an error of just over 1 gallon per ton in the final figure for the yield.

The yields obtained on the small hydraulic press used in the work described in this article have varied between 160–180 gallons per ton. These were surprisingly high in view of the low pressure used on the cheese, viz., approximately 60 lbs. per square inch. The pressure on a full-sized press is usually of the order of 100 lbs. per square inch and the yield of juice about 160 gallons after two pressings. It must be remembered, however, that the cheese as a whole, including the sacks and cloths, is very much smaller for the small press used in these trials and the juice can therefore be more easily expressed.

Chemical Composition of Juice. It is not proposed here to discuss the methods of analysis used at present for the quantitative determination of the individual constituents of the juice so examined. That will be more suitably done later in a separate paper concerned exclusively with that side of the work.

The usual constituents determined quantitatively have already been mentioned in the Introduction. To that list can be added—where the ‘bush’ cider fruit trials are concerned—determination of pH, total ash content and alkalinity of ash (expressed in terms of K_2O).

* Recorded as slight, medium, or full with + or — signs where necessary.

REFERENCES.

- (1) HOGG, R. and GRAVES BULL, H. G. *The Herefordshire Pomona*. Jakeman and Carver, Hereford. 1876—1885.
- (2) LLOYD, F. J. Report on Investigations into Cidermaking. Board of Agriculture and Fisheries. 1903. H.H. Stationery Office, London.
- (3) BALL, E. The Raw Material for Cidermaking. *Chemistry and Industry*. 10th Nov., 1945.
- (4) BARKER, B. T. P. The Production of Cider Fruit on Bush Trees. *Ann. Rept. Agric. and Hort. Res. Stn., Long Ashton*, p. 124, 1943.

SOME OBSERVATIONS ON THE STABILITY OF CIDERS AND PERRIES.

By B. T. P. BARKER.

I. INTRODUCTION.

In the following pages cider and perry may be considered as one for present purposes and the use of the term "cider" applies to both beverages.

It is common knowledge to those concerned with the making and handling of cider and perry that these beverages are very liable to suffer from a variety of disorders. Of these acetification will invariably occur unless certain precautionary measures are taken during the making period and subsequent storage life. Others—such as ropiness and sickness—are less general in their incidence and appear more or less irregularly, the outbreaks being associated with the vintages of particular years, varieties or districts.

As a result of investigations in France, Germany and this country, some information has been gained concerning the nature of the individual disorders and relating to certain control and curative measures, but the subject of the degree of susceptibility of individual ciders and perries has been given comparatively little attention. It is recognised in a general way that some are more resistant than others to the development of individual disorders and also that the juices from certain localities are likely to be of good or bad "keeping quality" as the case may be: but what are the fundamental factors determining the degree of natural stability of an apple or pear juice is a question on which there is little published information available to provide an answer.

The main purpose of this paper is, first, to give a brief review of the existing knowledge of the inherent natural factors—microbiological, chemical and nutritional—affecting the stability of cider and the susceptibility of individual ciders to the more common disorders. Particular attention is given to the development of cider sickness, acetification and ropiness. Also, series of observations made in 1944 on the development of acetification in bottled ciders after opening are recorded, since these appear to throw light on the subject of stability from an entirely new angle. Finally, there is a discussion of stability in relation to existing processing methods and suggestions for their improvement.

II. FACTORS AFFECTING THE GENERAL STABILITY OF CIDER.

A. Microbiological flora of cider.

The micro-organisms occurring in cider may be considered under three heads. First, those in the freshly-expressed juice; second, those active during processing and, third, those affecting the bottled product before and after opening. The first two classes are dealt with below; the last-named is considered later under IV.

1. Micro-organisms of the fruit and freshly expressed juice.

(a) *Yeasts*. Long before the apples reach the cider factory, the fruit is contaminated with a motley variety of organisms. True yeasts and torulas occur even in the sugary secretions of the nectar of newly-opened blossoms, as demonstrated by the writer in 1904. After petal-fall they persist throughout the development of the fruit: later, when the apples fall on to the ground, there are further opportunities of fresh accretions of these organisms. Hansen (5) has shown that it is at this season that the "wild" yeasts are most numerous in the orchard. Tests made at Long Ashton in 1907 with pure cultures of over a hundred of these yeasts added to apple juice sterilised before inoculation showed that they markedly affected the flavours of the resulting ciders.

(b) *Bacteria*. Acetifying bacteria are generally present on ripening fruits. Frequently, if apples are stored over-long, especially in sacks or deep heaps, heating takes place and a heavy infection develops. If the fruit thus mishandled is also badly bruised or damaged, a pronounced acetic taint may be discernible in the freshly-expressed juice.

It is probable also that the bacterium responsible for sickness (*maladie de la pousse*) occurs too on the surface of apples from certain orchards.

There is more doubt about the occurrence on fruit of the bacterium causing ropiness. Certain widespread outbreaks, such as that in the West of England in 1943, point to the occasional occurrence of the organism as a fruit infection: on the other hand, several outbreaks of ropiness in cider factories have arisen following the use of added sugar, which may carry bacteria of this class known to occur as natural contaminants from time to time.

(c) *Fungi*. Fungal infection of the newly-expressed juice is promoted by such factors as bruising, rotting and unsatisfactory storage conditions of the fruit. Species of *Penicillium* and other common saprophytes from rotted fruits may confer undesirable taints, particularly if a delayed onset of fermentation in the expressed juice gives time for mycelial development.

2. Microbiological changes during natural spontaneous fermentation.

(a) *The "apiculatus" stage*. Juices which undergo a normal process of alcoholic fermentation show the first signs of yeast activity within a few days of expression. Plate cultures from juices in the earliest stages of fermentation show an overwhelming preponderance of yeast colonies: bacterial colonies are very few. It is not unusual to find at least a dozen distinct species or varieties of yeasts present at this stage. The term "yeast" is here used to include true spore-forming yeasts, non-sporing *apiculatus* and other types, and *Torulæ*. The last-named are relatively sparse, but the *apiculatus* types are so common at this stage of fermentation that it is often termed the *apiculatus* stage.

(b) *The "dominant-yeast" stage*. As the more active stage of fermentation approaches, a contest develops for the nutrients present in the juice. Some micro-organisms may be completely starved or crowded out, others may persist in small numbers, while the more vigorous forms of yeasts—commonly from two to five in number—become dominant and exercise major control of the fermentation until one or more of the essential nutrients is exhausted. Yeast multiplication then slows down and ultimately the normal active alcoholic fermentation comes to a natural end.

(c) *The "Torula" stage*. With the cessation of the active stage of the normal alcoholic fermentation the natural maturation of the fermented liquor begins. During its course the numerical balance of the different types of

organisms undergoes a gradual change. Under the semi-starvation nutritional conditions resulting from the carbohydrate destruction and the removal of nitrogenous nutrients by the dominant yeast crop, cell autolysis develops to an increasing extent. The larger-celled organisms appear most affected and plate cultures show a reduced proportion of the dominant yeasts in relation to the smaller-celled yeasts, torulae and bacteria. Hence this stage has been termed the "Torula" stage.

3. Microbiological changes resulting from processing procedure for fermentation control.

What then happens to the surviving population of micro-organisms depends upon the actual composition of the cider after fermentation ceases or is artificially checked. This end-point is largely determined by the processing methods employed.

The course of events outlined under (2) for the spontaneous fermentation represents the simplest case,—one free from the complications introduced by the methods of fermentation control now in general use throughout the cider-making industry. Other than sulphuring, all such processes as racking, centrifuging, filtration and fining tend to upset the natural balance of organisms. Their general effect is (a) to reduce the proportion of the larger-celled dominant yeasts in relation to the smaller-celled yeasts, torulae and bacteria, *i.e.* to induce a premature "torula" stage and (b) to retain more fermentable material in the liquor for that stage than that present when fermentation is allowed to proceed to a natural end. Consequently these processes tend to weaken the natural stability of the cider at the critical stage when the protective effect of the active yeast fermentation is on the wane.

The bearing of these facts on the incidence of cider sickness and other disorders is further discussed below under III.

B. Nutritional factors.

It has been already shown that a wide variety of micro-organisms can grow in apple juice. So far as is known the only nutritional deficiencies affecting the maintenance of cider stability are those of nitrogen compounds in the juice and prepared ciders and of carbohydrates in the latter.

1. *Nitrogen.* The total combined nitrogen content of freshly-expressed apple juice ranges from 0.002 to 0.03% in different juices. In general, any juice containing 0.01% nitrogen and upwards is sufficiently well supplied to permit of continued yeast growth to complete the conversion of sugar into alcohol. A nitrogen content of less than 0.01% results in partial nitrogen starvation for the yeasts; not only are they slow in starting into growth but they often cease activity before all the fermentable sugars are converted and the resulting cider is thus a naturally sweet one.

In actual practice, makers desiring to retain natural sweetness in their ciders reduce nitrogen content artificially by removing some or all of the yeast crop during the stage of active fermentation by methods mentioned in the preceding section. Yeast during its growth absorbs and assimilates nitrogen: so the processes of racking, centrifuging and filtration, by removing the nitrogen-containing yeast cells, bring about a reduction of the nitrogen content of the juice. The subsequent rate of fermentation is thus reduced not only by the removal of the yeasts but also as a result of the lowered nitrogen content of the juice.

Nitrogen starvation of the yeasts does not necessarily imply nitrogen

starvation conditions for the bacterial population. For example, outbreaks of the bacterial disorder, cider sickness, occur most frequently and readily in low-nitrogen juices as the yeast fermentation declines: high-nitrogen ciders possess a greater measure of stability against this disorder. Acetification and ropiness seem also favoured particularly by low-nitrogen juices and ciders.

2. *Carbohydrates*. The disorders of sickness and ropiness are still more dependent on the presence of carbohydrates, as these are the materials attacked by the causative bacteria. When ciders are fermented practically to dryness, the natural sugars are almost entirely converted into alcohol. The alcohol, if present in sufficient concentration, supplements the effect of the low carbohydrate content in stabilising the cider against sickness and ropiness and, at high strength, even against acetification.

C. Chemical factors.

1. *Acids*. The predominating naturally-occurring acid of cider is malic. The titratable acidity of individual apple juices and ciders ranges usually from 0.15 to 1.5%, expressed as malic acid: the pH range is 3.2–4.5. The development of yeasts, acetifying bacteria and ropiness organisms appears relatively little affected by acidity. On the other hand, the sickness bacillus does not usually establish itself in ciders of 0.5% titratable acid content or over.

2. *Tannins*. "Tannin" contents of English juices range usually from 0.1 to 0.6%. Claims have been made that the "tannins" of cider possess definite antiseptic properties, but a wide experience of English ciders does not give the writer adequate support to endorse such claims. Very frequent examples of both acetification and sickness in ciders with a tannin content of more than 0.4% have been observed. The various factors involved in the action of tannins on micro-organisms—both directly and also indirectly through the possible effects of those substances on enzyme activity and the nitrogenous constituents of the juices—are too complex to permit of a dogmatic statement on the preservative value of these substances.

3. *Pectins*. Clarification of juices before or during the early stages of fermentation occasionally occurs naturally, when the liquor is said to "drop bright." This is the result of the spontaneous formation of a pectin clot in which is imprisoned practically the whole of the micro-organisms of the liquor. The clot slowly contracts and the contained liquor is slowly extruded, thus undergoing an exceptionally efficient form of clarification. Under favourable conditions and careful control it can be obtained brilliantly clear, easy to manage and with entirely favourable conditions for stabilising, providing that subsequent infection is avoided.

In the fruit juice industry, a comparable clarification is produced by the addition of a pectin-decomposing enzyme. The application of this method to cider-making is feasible, and a juice thus prepared could be fermented by a suitable yeast added in pure culture. This would give an increased chance of stability to the cider produced by this process.

No other significant effect of the pectins in relation to the stability of cider has been recorded yet.

III. FACTORS AFFECTING STABILITY AGAINST CIDER SICKNESS.

Ciders most liable to sickness are those of less than 0.25% acidity, of low nitrogen content, and with some unfermented carbohydrate present. The general features of the disorder have been described by Barker and Hillier

(2). Although the sickness bacillus seems to be very generally present in freshly expressed juices the risks of an outbreak are inversely proportional to the activity of the yeasts present. Such outbreaks as do take place occur after the normal alcoholic fermentation subsides: if such fermentation can be extended over a prolonged period the outbreak is indefinitely deferred or entirely averted. For instance, a susceptible cider filtered in December-January and bottled in January for natural conditioning is much more likely to remain free from sickness than if bottling is deferred to April, when there is a grave risk of an outbreak occurring with the onset of summer temperatures.

The degree of protection against sickness afforded by yeast action is not due to carbon dioxide, since the sickness organism itself forms this gas freely: it is more probably due either to the production by the yeast of bacteriostatic substances and/or to the fact that the bacteria are deprived by the yeast of some material essential to their growth. Various observations support the view that this may be oxygen. For example, ciders stored in the wood are more liable to sickness than those in bottle: again some ciders in cask remain sound as long as they are undisturbed, but if racked into fresh casks or bottled they develop sickness.

Whichever may be the cause of the protective action, it is evident that the "age" of the cider—meaning the degree of exhaustion of the yeast population—is a determining factor in outbreaks of sickness. A similar effect has been demonstrated (Barker and Grove, 1924) between "age" and outbreaks of a disorder of unknown cause resulting in the development of a "cooked" flavour in ciders of high-acid content.

IV. FACTORS AFFECTING STABILITY AGAINST ACETIFICATION AFTER BOTTLING.

The appearance of acetification in any cider left exposed to air after its primary active fermentation has ceased would be expected within a few weeks by experienced cider makers unless the liquor was treated with a preservative. The following observations made during 1944-5 show that this generally accepted statement must now be qualified.

These observations relate to the ciders described in Progress Report II in this Report. The fruit used was milled at a standardised condition of ripeness, and two gallons of each juice was used for trial. The juices were fermented in glass jars, centrifuged at 1.025 S.G., Seitz-filtered, and bottled direct from the filter into SO_2 -treated champagne pint bottles which were then stored in a cool cellar. The respective ciders were in nearly all cases bottled within the period Nov. 1943—Feb. 1944. Each cider was examined three times (1) in May 1944, (2) between July 26 and Aug. 3, 1944, (3) between Dec. 14, 1944, and Jan. 24, 1945, a freshly opened bottle being used on each occasion. After the bottles under test had been opened and the required sample of liquor withdrawn they were lightly re-corked in their half-empty condition and kept until April, 1945, in a laboratory at temperatures ranging from 60° to 90° F. During this time, examinations of the condition of the air-exposed residual liquor in these bottles were made on Sept. 12, Jan. 16 and April 25 respectively, *i.e.* at an interval of approximately four months after their original opening. Every bottle was further examined at the beginning of May, 1945.

The outstanding result in these trials was that more than 25% of these opened bottles showed no appreciable acetification up to May, 1945, although the liquor had been exposed to air for over 11 months. The alcohol content

was in almost every case normal (4-6½%), and there was no carbon dioxide held in solution in the ciders, as they were quite "flat" at the post-opening samplings. The majority of the non-acetified ciders did develop an appreciable increase in acidity apparent to the palate. Possibly, therefore, an acid fermentation of another type had taken the place of the usual acetification.

It is noteworthy that in several instances there was a development of *Penicillium* in these opened bottles. It was most marked in the samples which had been longest in bottle before the initial opening: thus, for the 46 ciders examined in three comparable series of random samples of increasing age, those showing *Penicillium* growth numbered 1, 4 and 17 respectively. This frequency distribution suggests that the fungus infections were not due to chance air-borne contamination but that all the bottles contained spores which grew only on exposure under favourable conditions. As throughout the whole series *Penicillium* and the acetifying bacteria showed themselves to be antagonistic organisms in this post-opening phase, it seems likely that the increase in *Penicillium* growth was due to a loss of vigour by the acetifying bacteria proportional to the length of time that the bottle had remained unopened.

A definite correlation between acetification and the nitrogen content of the trial ciders could be traced in the samples of the series bottled earliest, i.e. before the yeasts had "aged." The general conclusion suggested is that acetification occurs most quickly and intensely in the ciders from juices with an original content of less than 0.01% total nitrogen. Above that figure the tendency to acetification lessened as the nitrogen content increased.

In accordance with the relationship existing between nitrogen content and rate of fermentation, it follows that the tendency of a cider to acetify in its later life will vary inversely with the rate of fermentation of the juice: further, that the longer a cider is permitted to "age" in a full air-tight container without exposure to air the greater the resistance to acetification on exposure.

V. FACTORS AFFECTING STABILITY AGAINST ROPINESS.

As with sickness, ciders most liable to ropiness are those of low acidity—0.25% malic acid and less—low nitrogen content, and with some unfermented carbohydrate.

The ropiness organism isolated by Grove from cider (4) was shown by him to be incapable of growth in nutrient media containing 0.8% of malic acid and over, while only very slight growth occurred in the presence of 0.6% malic acid.

As regards the nitrogenous requirements of this organism he found that while it developed well in neutral or slightly acid bouillon and in yeast water with added glucose it failed to develop in malt extract. This suggests some degree of selectivity as regards the nature of the nitrogenous compounds which it can assimilate and proves that suitable sources of nitrogen occur among the products of yeast autolysis. The latter is in conformity with practical experience in cider making, where ropiness frequently appears to be associated with prolonged standing on the lees. Thus, as a practical measure of precaution against the establishment of this disorder in a cider, removal of the sedimentary yeast before autolysis becomes pronounced is indicated.

It is quite possible that the natural nitrogenous constituents of apple juice are not suitable sources of nitrogen, since the present writer has failed

to induce ropiness in sterile juices infected with a recently isolated ropiness bacillus, although ropiness has been produced in some unsterilised ciders similarly infected where yeast autolysis has occurred.

VI. DISCUSSION.

Reviewing the subject of stability in ciders in the light of the information given above, the following general picture emerges. As presented, it does not take into account those cases in which by some special form of treatment, *e.g.* pasteurisation, filtration through germ-proof filters and the use of preservatives, the micro-organisms present in the freshly-expressed juices are entirely removed or put out of action: it does, however, include the cases of their partial removal by the processing methods adopted in ordinary practice, such as washing the fruit, keeving, racking, the use of finings, centrifuging, and clarification by the ordinary types of filters.

Subject then to these qualifications, all ciders must be regarded as naturally susceptible to attack by several types of widely-distributed micro-organisms. Malic acid, when present in amounts exceeding 0.6% acts as a deterrent to cider sickness and, possibly, other bacterial disorders not referred to in this paper; the tannins may have slight restrictive action and alcohol may have a very slight preservative effect, but only if the original juice was of exceptionally high specific gravity, *e.g.* more than 1.075. Normally, then, ciders and perries of a potable grade of palatability contain no constituents which in the quantities ordinarily present possess adequate preservative powers against the disorders to which they are subject.

Notwithstanding this general susceptibility there is evidence that differences exist due to at least three factors acting in combination (1) the nature of the composition of the cider (2) the degree of yeast activity, and (3) the "age" of the cider. Probably the organisms of all the commonly occurring disorders are present from an early stage in the life of a cider and it depends upon the age of the sample as to which individual disorder becomes established when and if conditions permit of its development.

The position of cidermakers in their endeavour to produce a sound and stable beverage is thus difficult. An outbreak of one or more such disorders may occur in their product, particularly during the making season or in the subsequent period extending to the following summer. These attacks may occur in spite of every care and vigilance on their part. None of the usual lines of production open to them is without drawbacks. If they proceed with normal methods, they must accept the risk of attack. If they decide to try to eliminate this risk by the use of preservatives, the only one permissible is sulphur dioxide and this may not be used at a sufficiently high dosage to guarantee immunity. Pasteurisation cannot be adopted without an appreciable effect on flavour in the types of cider most in demand, where the acidity of the liquor is of a degree rendering the flavour change to the "apple-pie" character readily detectable. Filtration through bacteria-proof filters is slow and expensive and does not always achieve its purpose. Fortification by raising the alcoholic strength through addition of sugar prior to ordinary fermentation might create complications with the Excise authorities and possible taxation of the beverage as a wine.

It may be that the methods successfully developed in the past 15 years for the production of non-pasteurised unfermented apple juice as a beverage point the way to a solution of the cidermakers' problem. A discussion of these methods lies outside the scope of this article: readers desiring detailed

information are referred to the bulletin on Fruit Products by Charley and Harrison (3). At present their application to cider production is limited by two considerations—(1) they concern only the bottled product and (2) the heavy capital outlay on the requisite plant and equipment and the increased costs of production necessitate a high price for the product. At present a large percentage of the cider output is sold in cask as draught cider and the selling price possible for such cider is governed by that of draught beer.

Whatever process of cider-making is employed, the hygienic conditions of the plant play a major part in the incidence of undesirable infections during processing. Although factory conditions have been greatly improved during recent years by progressive makers, much still remains to be done to provide the standard of buildings, equipment and working conditions under which the risks of infections are reduced to a minimum. The existence of a definite factory microbiological flora is a fact to be reckoned with. Only systematic and regular disinfection of the premises and of all vats, casks and surfaces of plant and equipment with which the liquor may come into contact will serve to keep factory infection under control.

It has previously been pointed out that one of the probable factors essential for the development of cider sickness is oxygen. Outbreaks of sickness under strictly anaerobic conditions have not been recorded, although for the initiation of this disorder traces only of oxygen seem to be required. Therefore, when air is kept from access to the liquor—more especially after normal yeast fermentation has passed a certain point—the outbreak of the commoner disorders such as acetification and sickness is unlikely, perhaps even impossible.

Thus, as a reliable safeguard against the disorders to which cider is subject, some modification of processing is desirable in the direction of preventing access of air to the liquor by displacing air by carbon dioxide. This has been achieved already by one system of processing—the Redox method—which in some preliminary trials has given very promising results. This method is open to the economic objections already noted for apple juice production and therefore can only be utilised at present for the preparation of the higher priced grades of bottled cider. It, and any other methods based upon the exclusion of oxygen during the later stages of active fermentation and onwards, stand, however, as the surest existing means of securing stability of the bottled product.

SUMMARY.

1. The existing knowledge of the inherent natural factors—microbiological, chemical and nutritional—affecting the stability of ciders and perries and their susceptibility to the more common microbiological disorders is briefly reviewed. Special reference is made to the incidence of sickness, acetification and ropiness.

2. Observations are recorded of the behaviour of a series of 46 different bottled ciders of known history and composition made in the 1943 season in respect of their susceptibility to the development of micro-organisms after the bottles were opened in May, 1944, and their contents exposed to contact with air for prolonged periods. Corresponding tests were made on two subsequent occasions, when the respective ciders were approximately three and seven months older in bottle before being opened. Of the 138 bottles thus under test, over 25% remained up to May, 1945, unacetified to a degree perceptible to the palate or nose. There appears to be a definite positive correlation

between the "nitrogen" content of the original juice and the resistance of the cider to acetification. The liability to the growth of *Penicillium* in the exposed ciders becomes much greater as the age of the bottled cider increases, while the vigour of the acetic organisms appears to lessen.

3. On the basis of the facts now available the conclusion is reached that to ensure the highest possible degree of stability in ciders and perries without pasteurisation or addition of preservatives the existing processing methods need modification from the time when the primary active alcoholic fermentation begins to wane. The suggested modifications involve the complete exclusion of air from the liquor by its displacement with carbon dioxide and the removal of sedimentary yeast before autolysis becomes appreciable.

REFERENCES.

- (1) BARKER, B. T. P. and GROVE, O. (1924). Some investigations on the bottling of cider *Long Ashton Ann. Rept.*, 1924, 70-91.
- (2) BARKER, B. T. P. and HILLIER, V. F. (1910). Cider sickness. Paper read at British Association meeting at Portsmouth. (Abstract in *Long Ashton Report*, 1911, 42-48).
- (3) CHARLEY, V. L. S. and HARRISON, T. H. J. (1939). Fruit juices and related products. *Imp. Bur. Hortic. Tech. Comm.*, 11, pp. 104.
- (4) GROVE, O. (1917). A ropy cider bacillus. *Long Ashton Ann. Rept.*, 1917, 15-17.
- (5) HANSEN, EMIL (1911). *Gesammelte Theoretische Abhandlung über Gärungsorganismen*. Jena : Gustav Fischer.

THE APPLE AS A SOURCE OF VITAMIN C.

By A. POLLARD, MARGARET E. KIESER and JOAN D. BRYAN.

In recent years a considerable interest has been taken in sources of Vitamin C, and many uncommon fruits and vegetables have been analysed in a search for foodstuffs rich in the vitamin and capable of supplementing the war-time diet. The apple, the commonest English fruit, has received little attention, for the general impression has been that its Vitamin C content is low. Analyses of apple varieties have, however, been made over a number of years and as early as 1931 Bracewell and others (1) showed by feeding tests that apples contained Vitamin C and that Bramley's Seedling was comparatively rich, the highest concentration being in the peel. This was confirmed by Birch *et al* (2), who found that this variety gave figures of 16 mg. per 100 g. for the cortex and 77 mg. for the skin : the cortex of other varieties contained much smaller amounts, *e.g.* 1.6 mg. in Cox's Orange and 5.3 mg. in Newton Wonder. Olliver in 1936 (3) obtained values for Bramley's Seedling very similar to those obtained above.

One of the main reasons why the apple has received little attention as a source of Vitamin C is the fact that little is found in the juice. It was shown by Fawns and Martin (4) and confirmed by experiments at Long Ashton (5) that apple juice and cider contained little Vitamin C, only in Bramley juice were appreciable amounts present. It was found by these workers that the ascorbic acid (Vitamin C) in the fruit is rapidly oxidised to dehydro-ascorbic acid when the cells are ruptured, so that little ascorbic acid as such finds its way into the juice.

In the last two years interest in the Vitamin C content of apples has again revived and the more recent published values suggest that some of the common varieties are by no means poor sources of the vitamin. The ranges of values found by some workers in different countries are briefly summarised in Table I and are expressed as mg. per 100 g. fresh tissue.

TABLE I.

Source of Material					Vitamin C	Reference
England	..	..	..	..	18.7—33.7	(6)
America	..	..	..	..	6.9—20.0	(7)
New Zealand	..	..	..	..	1.9—35.9	(8)
Sweden	..	..	..	..	8.3—34.5	(9)

The high values in the English and Swedish tests were given by Bramley's Seedling and in the New Zealand tests by Sturmer Pippin. In the Swedish tests Wellington had almost as high a Vitamin C content with about 30 mg. per 100 g. It is therefore evident that certain varieties of apple can attain Vitamin C contents little inferior to those of citrus fruits.

During the past season tests on Vitamin C content of apples have been made at Long Ashton, although the number of varieties available has been restricted owing to the effect of the disastrous spring frosts. The experiments will be briefly described.

Method of Analysis.

Fruit was analysed soon after the time of picking and samples were taken from a bulk of 2 to 3 lb. by cutting sectors from opposite sides of each fruit. The sections were placed as cut into a tared vessel containing 5% metaphosphoric acid and after weighing were disintegrated in a Waring Blendor. The clear fluid which separated on short standing was then titrated with indophenol in the usual way. Titrations carried out on several samples by the method using formaldehyde (10) showed that interfering reducing substances were virtually absent. For example, in an extract of Chisel Jersey skin the true ascorbic acid amounted to over 98% of the total indophenol reducing substances. Small amounts of dehydro-ascorbic acid were present in some varieties, equivalent to about 5% of the total ascorbic acid.

Results.

The values found for a number of dessert, culinary and cider varieties are shown in Table II.

TABLE II.

Variety					Type			A.A. mg/100 g.
Blenheim	..	..	..	..	Dessert	..	..	6.3
Cox's Orange	..	..	..	..	"	..	..	5.7
Wyken Pippin	..	..	..	..	"	..	..	3.7
Laxton's Superb	..	..	..	..	"	..	..	5.0
Warner's King	..	..	..	..	Culinary	..	..	3.7
Beauty of Kent	..	..	..	..	"	..	..	6.5
Norfolk Beefing	..	..	..	..	"	..	..	10.0
Newton Wonder	..	..	..	..	"	..	..	10.4
Crawley Beauty	..	..	..	..	"	..	..	11.2
Edward VII	..	..	..	..	"	..	..	13.6
Bramley's Seedling	..	..	..	..	"	..	..	18.1
Medaille d'Or	..	..	..	..	Cider (bittersweet)	..	..	9.1
Dabinett	..	..	..	..	"	"	..	12.8
Tardive Forestier	..	..	..	..	"	"	..	21.3
Yarlington Mill (a)	..	..	..	..	"	"	..	25.2
" " (b)	..	..	..	..	"	"	..	34.1
Reine des Pommes	..	..	..	..	"	"	..	31.4
Chisel Jersey	..	..	..	..	"	"	..	34.0
Red Foxwhelp	..	..	..	..	" (sharp)	..	..	14.8

Discussion.

The values found for the dessert varieties are low and are of the order generally assumed valid for varieties other than Bramley's Seedling. The last-named again shows its pre-eminence among the common varieties tested; but some of the other culinary varieties are, however, also much higher in Vitamin C than the dessert types. The cider varieties show a considerable range of values, the highest values far surpassing the dessert and culinary types. High concentrations were found in the skin of the fruit, *e.g.* in Chisel Jersey the skin contained 72 mg. per 100 g.

The dessert varieties tested in 1945 give lower Vitamin C contents than the same varieties tested in Sweden (9), the values for Blenheim Orange and Cox's Orange being only about 6 mg. per 100 g. at Long Ashton, but 19.8—23.4 mg. and 14.1—16.4 mg. respectively according to the Swedish author. It is probable that the Vitamin C in a given variety is dependent on both site and season, as is the case with other fruits. The variation in tomato varieties from season to season is discussed elsewhere in this Journal (11). In a more favourable season the apple varieties listed in Table II may therefore show higher ascorbic acid values, but the results prove, nevertheless, that even in an unfavourable season, many of the common varieties can provide a significant contribution to the Vitamin C of the diet.

It is proposed to carry out further tests on these and other varieties in the coming season.

Summary.

1. A review of recent work suggests that the apple may be a better source of Vitamin C than has generally been supposed.
2. Tests carried out on apple varieties in the 1945 season show that some culinary and cider varieties are fairly good sources of Vitamin C, the cider varieties giving the highest values.
3. The values found are lower than those found by some workers in other countries and the differences may be ascribed to the effects of site and season.

Acknowledgments.

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REFERENCES.

- (1) BRACEWELL, M. F., KIDD, F., WEST, C. and ZILVA, S. S. *Biochem. J.*, **25**, 138, 1931.
- (2) BIRCH, T. W., HARRIS, L. J. and RAY, S. N. *Ibid.*, **27**, 590, 1933.
- (3) OLLIVER, M. *J. Soc. Chem. Ind.*, **55**, 153 T, 1936.
- (4) FAWNS, H. T. and MARTIN, E. J. *Ibid.*, **57**, 60, 1938.
- (5) CHARLEY, V. L. S. *Ann. Rept. Agr. & Hort. Res. Stn., Long Ashton*, 1938, p. 231.
- (6) WEST, C. and ZILVA, S. S. *Biochem. J.*, **38**, 105, 1944.
- (7) FISH, V. B., DUSTMAN, R. B. and MARSH, R. S. *Proc. Amer. Soc. Hort. Sci.*, **44**, 196, 1944.
- (8) KIDSON, E. B. *New Zealand J. Sci. & Tech.*, **25**, 134, 1943.
- (9) JENNERUP, E., *Fruktodlaren*. No. 2, 62, 1945. (*Hort. Abstr.*, Sept. 1945, No. 1302).
- (10) MAPSON, L. W. *J. Soc. Chem. Ind.*, **62**, 223, 1943.
- (11) POLLARD, A., KIESER, M. E. and BRYAN, J. D. *This Journal*, p. 203

FACTORS INFLUENCING THE COMPOSITION OF THE TOMATO.

A COMPARISON OF VARIETIES AND OF INDOOR AND OUTDOOR CULTURE.

By A. POLLARD, MARGARET E. KIESER, and JOAN D. BRYAN.

A study of some of the factors influencing the composition of the tomato was made in the 1944 season, the chief interest being in Vitamin C (ascorbic acid) content. The results, which have already been described (1), showed that of the factors studied, those with the greatest effect were differences due to variety and to growth indoors or outdoors. In the present trial a further study of these two factors has been made and tomatoes of several commercial varieties have been grown at the same time in the glasshouse and in the open air.

Material.

The plants were raised in a glasshouse and one batch of 13 varieties was planted out in rows in an open situation at the beginning of June in ground which had received a fertiliser dressing at the rate of 2 cwt. sulphate of ammonia, 4 cwt. superphosphate and 2 cwt. muriate of potash per acre. It was not possible to duplicate all the varieties in the glasshouse, but 9 of them were planted at the same time in large pots in a mixed compost with N.P.K. addition and stood in the centre of a glasshouse: 6 plants of each variety were taken for the glasshouse test. All plants were stopped at the fourth truss and standard spraying procedure was applied throughout. To eliminate as far as possible any differences due to position on the plant or due to variation between plants, combined samples were taken at random from as many plants as possible and about 2 lb. of fruit sampled for each analysis. In the majority of cases, each variety was tested 5 times during the season and analyses for ascorbic acid, sugar, free acid, dry weight and pH were carried out on each batch of fruit. As in the previous tests (1, 2), the analytical samples were taken by combining opposite sectors cut from each fruit and these were disintegrated in a Waring Blendor in the appropriate liquid.

Results.

Ascorbic Acid.

The ascorbic acid values for the varieties are shown in Table I and they are expressed as mg./100g. fresh weight. Each variety shows a considerable variation between the individual values, but no definite relation can be seen between the ascorbic acid level and the time of picking during the period of test from the end of August to the beginning of October. The averages for the varieties show, however, definite differences, with a range for indoor plants from 15.4 to 23.5 mg. and for outdoor plants from 20.1 to 25.6 mg. With the exception of Vetomold, which shows identical values for indoor and outdoor grown fruit, the values for indoor fruit are all lower than the values for the corresponding varieties grown in the open. These differences are above the level required for significance in the varieties Moneymaker, Early Market, Market King and Manx Marvel; for the other varieties the differences are not significant owing to the rather large individual variations within the varieties.

In Table II the varieties are set out in the order of their ascorbic acid

contents, those not included in the glasshouse test being put in brackets. In general, the varieties showing the highest values under glass are also highest out of doors. For example Golden Perfection, Moneymaker and Manx Marvel are high in each case while Open Air, Market King and Early Market are low under both conditions. The other varieties take up intermediate positions.

The differences between varieties at the top and bottom of the tables are found to be significant, *e.g.* Moneymaker and Golden Perfection are each significantly higher than Early Market or Market King, both under glass and out of doors. The relative positions of the varieties at the extremes of the tables may therefore be taken to be established, although the varieties with intermediate values are not significantly different in their ascorbic acid levels.

Sugar.

As shown in Table II, the amount of sugar in the fruit also varies according to variety and to growth indoors or outdoors. In all cases, the value found for a variety grown in the glasshouse is greater than the value for the variety grown out of doors, the differences being greater than the significance level for Moneymaker, Premier, Plumpton King, Vetomold and Golden Perfection. The differences between the varieties with the highest sugar contents and those with the lowest contents were again found to be significant; *e.g.* in both indoor and outdoor plants, Early Market and Plumpton King were found richer in sugar than Vetomold, while Golden Perfection was richer in sugar than Market King under both conditions.

Acid.

The amount of titratable acid in the fruit was found, as with the amount of sugar, to be higher in the glasshouse grown fruit, the differences being significant in all varieties except Early Market. As before, the varieties do not all appear in the same order in the table under the two conditions, except that Vetomold is lowest in acid in both. The varieties at the top of the table are found to be significantly richer in acid than those at the bottom, *e.g.* Plumpton King and Market King are significantly higher than Golden Perfection or Vetomold when grown indoors, and Early Market and Premier are significantly higher than Essex Wonder or Vetomold when grown out of doors.

pH.

The indoor grown fruit with the higher acidities had the lower pH values, from 4.00 to 4.10; the fruit with the lower acidities had pH values from 4.16 to 4.21. As would be expected, the outdoor grown fruit with lower acidities had pH values higher than the corresponding fruit grown under glass. In the fruit grown out of doors, however, there was less direct relation between acidity and pH.

Dry Weight.

High dry weight was found to correspond with high sugar and high acid, while low dry weight corresponded with low values for these constituents. The dry weight figures for indoor plants were higher than those for outdoor plants, but the differences were not sufficient for significance. The values for each variety showed considerable variation and sugar and acid appeared to vary independently of each other.

Flavour.

Flavour ratings to a maximum of 5 were awarded to each sample of fruit at the time of analysis, marks being deducted for excess acidity, insipidity or

lack of characteristic tomato flavour. The average for indoor grown fruit was 3.7 and the average for the same varieties grown out of doors was 3.2, many of the latter being rather insipid. For indoor fruit the varieties receiving the highest ratings were found to be those with both high sugar and high acid, *e.g.* Early Market, Golden Perfection and Plumpton King. The varieties receiving lowest awards for flavour were those with the lowest values for sugar and acid, *e.g.* Open Air and Vetomold. No apparent relation could be found between flavour and acid/sugar ratio. In outdoor grown fruit little relation could be found between flavour and acid and sugar content.

Discussion.

The effect of cultural treatment.

Some of the findings of other workers on the factors influencing the composition of tomatoes were discussed in the previous papers (1, 2). Considerable effects were found to be produced by differences in variety, but in many trials even greater effects were produced by differences in site. The effect of site has appeared to be mainly that of climate and particularly of sunlight, for manurial effects have been found to be small. The effect of glasshouse treatment in lowering ascorbic acid levels has therefore been attributed to the effect of shading or the reduction of light intensity. Further evidence on this point has been brought forward by Hamner and co-workers (3) who found that moving plants from light to shade during the fruiting period depressed the ascorbic acid level of the fruit; conversely, moving the plants from shade to light brought about the reverse effect. When, however, the light under glasshouse conditions was equivalent to 90% of that in the open, the fruit grown in the glasshouse was not lower in ascorbic acid than fruit grown in the open. The effect of illumination has been further shown by tests on individual fruits carried out by Kidson (4) and by McCollum (5), who found that the portion of the fruit exposed to light had a higher content of ascorbic acid than the more shaded portion.

In the present 1945 Long Ashton trials, the general level of ascorbic acid was low and the two varieties Market King and Ailsa Craig grown out of doors gave values of 20.2 and 20.1 mg. per 100 g. respectively, as compared with the corresponding values for these varieties in 1944, *viz.* 35.0 and 34.8. The low levels during 1945 may probably be associated with the dull weather prevailing during the time of picking, for the total hours of sunshine during the months of August, September and October were 347. The figure for the corresponding period in 1944 was 471, while the average for the 20 year period was 432. The greatest difference in ascorbic acid observed in the 1945 season between fruit of a given variety grown out of doors and in the glasshouse was 5.7 mg. for Moneymaker; Market King only showed an average difference of 3.3, but in 1944, this latter variety showed a difference of 15.9 mg. between the two treatments. The conditions of illumination may therefore have been more nearly equal in the glasshouse and out of doors in the 1945 period with its low sunshine record.

While growth in the glasshouse has, in this trial, given lower levels of ascorbic acid, the effect on sugar and acid and also on flavour has been in the reverse direction, the glasshouse fruit being superior in these respects. The effect on these factors may be that of temperature rather than that of illumination. The different varieties show varying responses to the effect of glasshouse as against open-air treatment. Although under both conditions Early Market and Market King were given a high flavour score and Vetomold a low

TABLE I.
ASCORBIC ACID IN TOMATO VARIETIES.

Variety	Indoor or outdoor	Ascorbic acid mg./100g.						Mean	Standard Deviation	Significant Difference
		22.4 25.8	22.0 21.6	18.7 25.4	17.9 29.6	18.7 —	—			
Moneymaker	in out	22.4 25.8	22.0 21.6	18.7 25.4	17.9 29.6	18.7 —	—	19.9 25.6	0.936 1.633	4.44*
Early Market	in out	15.0 20.5	17.5 21.2	14.0 20.8	15.6 18.8	15.0 23.1	—	15.4 20.9	0.580 0.690	2.08*
Open Air	in out	18.1 27.8	16.1 20.2	14.8 20.8	15.9 16.5	13.6 19.9	23.8 —	17.0 21.0	1.482 1.849	5.36
Premier	in out	17.6 26.1	13.0 20.6	18.3 19.2	19.4 24.4	24.6 22.9	—	18.6 22.6	1.858 1.248	5.16
Plumpton King	in out	18.7 25.3	21.9 17.6	17.8 20.2	15.4 22.8	17.4 22.2	—	18.2 21.6	1.063 1.293	3.86
Vetomold	in out	22.5 22.4	22.8 23.9	20.9 22.6	20.7 17.9	20.7 22.0	23.2 —	21.8 21.8	0.472 1.017	2.54
Market King	in out	18.7 19.2	16.8 22.4	15.9 18.5	15.5 20.5	17.6 20.6	—	16.9 20.2	0.580 0.671	2.04*
Golden Perfection	in out	27.7 24.6	25.5 25.4	23.0 26.2	21.1 27.4	20.2 22.1	—	23.5 25.1	1.389 0.890	3.80
Manx Marvel	in out	22.4 25.9	18.2 30.6	17.9 24.1	16.8 20.8	19.1 18.4	—	18.9 24.0	0.954 2.098	3.42*
Sunrise	out	23.4	22.0	18.4	22.8	16.7	—	20.7	1.317	
Potentate	out	28.8	24.9	26.4	22.8	19.2	—	24.4	1.631	
Ailsa Craig	out	21.1	20.2	19.3	20.4	19.4	—	20.1	0.335	
Essex Wonder	out	22.9	22.7	22.6	20.0	25.8	—	22.8	0.919	

* Indicates that difference between means for indoor and outdoor is significant.

TABLE II.
ASCORBIC ACID, SUGAR AND ACID IN TOMATO VARIETIES.

Indoor Plants.

Outdoor Plants.

Ascorbic Acid		Sugar		Acid		Ascorbic Acid		Sugar		Acid	
Variety	mg./100g	Variety	%	Variety	N mL. 10 per 100g	Variety	mg./100g	Variety	%	Variety	N mL. 10 per 100g
Golden Perfection	23.5	Golden Perfection	3.32	Plumpton King	92.0	Moneymaker	25.6	Early Market	3.12	Early Market	66.9
Vetomold	21.8	Early Market	3.28	Market King	88.2	Golden Perfection	25.1	Manx Marvel	3.02	Premier	62.5
Moneymaker	19.9	Plumpton King	3.21	Moneymaker	87.4	(Potentate)	24.4	Golden Perfection	2.96	Manx Marvel	61.9
Manx Marvel	18.9	Manx Marvel	3.17	Early Market	87.0	Manx Marvel	24.0	(Potentate)	2.80	Open Air	58.2
Premier	18.6	Premier	3.09	Manx Marvel	85.4	(Essex Wonder)	22.8	(Sunrise)	2.79	Golden Perfection	58.1
Plumpton King	18.2	Moneymaker	3.09	Premier	83.4	Premier	22.6	Plumpton King	2.78	Moneymaker	58.1
Open Air	17.0	Market King	2.89	Open Air	75.6	Vetomold	21.8	Premier	2.70	(Sunrise)	57.1
Market King	16.9	Open Air	2.86	Golden Perfection	71.1	Plumpton King	21.6	Market King	2.66	Market King	57.1
Early Market	15.4	Vetomold	2.75	Vetomold	64.3	Open Air	21.0	Open Air	2.59	Plumpton King	57.1
						Early Market	20.9	Moneymaker	2.56	(Ailsa Craig)	50.6
						(Sunrise)	20.7	(Ailsa Craig)	2.55	(Potentate)	50.5
						Market King	20.2	(Essex Wonder)	2.50	(Essex Wonder)	49.1
						(Ailsa Craig)	20.1	Vetomold	2.49	Vetomold	48.7

score, Golden Perfection was rated high when grown indoors and low when grown out of doors.

The effect of variety.

Although the ascorbic acid content of tomatoes is seen to be affected by cultural conditions and by fluctuations within a given variety, the results obtained also show real differences between many of the varieties. In the present series the range of average values for indoor grown fruit of different varieties was from 15.4 to 23.5 mg. per 100 g., while for outdoor grown fruit the corresponding range was from 20.1 to 25.6 mg. Other workers have found yet greater variations, *e.g.* MacLinn and Fellers (6) in a study of 98 varieties obtained values ranging from 13 to 44 mg. per 100 g. Although the level for a given variety was not constant from season to season, the varieties still showed similar relative differences.

In the Long Ashton trial the varieties giving the highest values for ascorbic acid, under both indoor and outdoor conditions, were Moneymaker and Golden Perfection, while Market King and Early Market were low under both conditions. On the other hand, the last two were rated high for flavour. When grown under glass, Golden Perfection was high in both ascorbic acid and flavour score, but when grown in the open the flavour was much poorer. The only variety which remained consistently high in both ascorbic acid and flavour score was Moneymaker. It would be inadvisable, however, from the results obtained in one season, to point to any one variety as being outstanding in general quality: and furthermore, factors such as cropping capacity and resistance to disease are to be taken into account. Further studies will be carried out on some of the varieties showing the greatest differences in these tests.

Summary.

1. Significant differences were found between tomato varieties in their content of ascorbic acid, sugar and acid.

2. Tomatoes grown in the glasshouse were lower in ascorbic acid than when grown in the open air, but the production of sugar and acid was higher in the glasshouse and the flavour was superior.

3. Varieties showing the highest production of ascorbic acid under indoor and outdoor conditions were Moneymaker and Golden Perfection, while Open Air, Market King and Early Market were low in each case.

4. In flavour, which was associated with high sugar and acid content, Early Market and Market King were in the higher category both in the glasshouse and in the open, while Vetomold was low under both conditions.

5. When grown under glass, Golden Perfection was high in both ascorbic acid and flavour, but when grown in the open, although still high in ascorbic acid, the flavour was poor. The only variety which remained consistently high in both ascorbic acid and flavour was Moneymaker.

Acknowledgment.

We are indebted to Mrs. J. Tolhurst for much assistance in the analytical work.

REFERENCES.

- (1) POLLARD, A., KIESER, M. E., and BRYAN, J. D. *Ann. Rept. Agricultural and Horticultural Research Station, Long Ashton*, 1944, p. 171.
- (2) POLLARD, A., KIESER, M. E., and STEEDMAN, J. *Ibid.*, p. 179.
- (3) HAMNER, K. C., BERNSTEIN, L., and MAYNARD, L. A. *J. Nutrition*, **24**, 85, 1945.
- (4) KIDSON, E. B. *New Zealand J. Sci. and Tech.*, **25**, No. 3 (Sec. B), 129, 1943.
- (5) MCCOLLUM, J. P. *Proc. Amer. Soc., Hort. Sci.*, **45**, 382, 1944.
- (6) MACLINN, W. A. and FELLERS, C. R., *Mass. Agr. Expt. Sta. Bull.* No. **354**, 1938.

FACTORS AFFECTING QUALITY IN POTATOES. II.

By A. POLLARD, MARGARET E. KIESER, ALICE CRANG and T. WALLACE.

The experiments reported herein are in continuation of those described in the Report for 1944 (1).

In 1945 it was possible to examine samples from manurial trials at five centres, three of which were also included in the 1944 trials. In addition, samples were examined from two "claying" experiments and from a special series of sand cultures dealing with relationships of K, P and Fe.

The results for 1945 largely confirm those obtained in 1944 in showing the importance of site and variety, and the limited improvements which may be induced by manures on sites where quality is initially poor.

In particular, it is again shown that where blackening is severe under conditions of potash deficiency, manuring with potassic fertilisers, either as sulphate or muriate, improves the colour, whilst nitrogenous fertilisers may increase blackening.

At one centre where severe phosphate deficiency was observed, phosphatic manuring did not affect the blackening problem.

In the sand culture experiment deficiency of iron and a high level of phosphorus respectively resulted in a yellow colouration of the boiled tubers.

The tests again showed the high susceptibility of Majestic to blackening.

Methods.

The methods used in 1945 were similar to those described in the 1944 tests, tubers of average specific gravity being selected from each sample for the cooking tests.

FIELD OBSERVATIONS AND RESULTS OF COOKING TESTS.

(a) Field Observations.

Centre I. Long Ashton.

Plot 12. This is a long period rotational manurial experiment. The field results for the 1945 potato crop are given in full in this Report, page 95. It will be clear from the field account that serious deficiencies of N, K and Mg resulted from certain of the manurial treatments in the main block and that on the plots receiving chlorides toxic chloride effects were produced on the haulms, though yields were of a high order.

Plot 17a. The details regarding soil and manurial treatments for this plot were given in the account of the 1944 experiments (1, p. 186). In 1945 the potatoes were grown as one of a number of crops on the plots, the manures being as in 1944. The outstanding feature was again the serious potash deficiency resulting from the treatments no manure and N.P. Symptoms of mild nitrogen and magnesium deficiencies also occurred on certain plots as in 1944.

Centre II.

Fertiliser Experiment. This centre was located on a site near Centre A of the 1944 experiments and on a similar light Black Fen peat. The experiment was a repetition of the 1944 trial.

Observations of the crops made on July 26th, 1945, showed that the —K

effects on growth were less than in 1944 and slight effects of —P and —N could also be seen.

Claying Experiment. The soil is similar to that used for the fertiliser trial but appeared to be somewhat calcareous, arising from natural Fen conditions. Early in the season plots not receiving claying treatment showed some evidence of manganese deficiency. Vigour over the whole area was only moderate during July.

Centre III.

Claying Experiment. Precise data are not available for this centre, but it is another example of a light Black Fen soil as at Centre II, considered likely to be improved by claying treatment.

Centre IV.

This centre in the Cotswold area is located near Centre F in the 1944 trials. The soil is derived from the Inferior Oolite formation and the field, previously derelict, had carried two cereal crops after reclamation prior to potatoes. The fertiliser treatments comprised the application of N, P and K in different combinations and at three different levels, viz. sulphate of ammonia at 0, 2 and 4 cwt. per acre, superphosphate at 0, 3 and 6 cwt. per acre and muriate of potash at 0, $1\frac{1}{2}$ and 3 cwt. per acre.

The only outstanding deficiency symptom observed in the haulm was that due to lack of K (see this Report, p. 72). The symptoms of K deficiency appeared late in the season in all plots which did not receive K dressings and especially where the heavier application of N was given.

Centre V.

Soil conditions and manurial treatments at this centre were given in the 1944 Report (Centre C, p. 191). The fertiliser treatments (but not the lime treatments) were repeated for the 1945 potatoes. The growth features of the crop were marked in some detail for each plot on Aug. 1st, 1945, when the following points were in evidence.

No lime plots: growth was very poor and all plots showed severe effects of calcium deficiency.

Limed Plots:

No Manure: growth generally poor and symptoms of either —K or —P or both prevalent.

N.P.K.: growth generally good, but —Mg symptoms generally shown.

P.K.: growth variable, —Mg symptoms prevalent.

N.K.: growth only moderate

N.K.: growth only moderate and —P effects often strongly marked; also occasional —Mg symptoms.

K.: similar to N.K.

N.P.: growth variable and generally only moderate with —K symptoms prevalent.

P.: similar to N.P.

The general point may also be made that there appeared a definite gradient relative to —K and —P effects across the fertiliser treatments, which could be observed by comparing the duplicate "no manure" plots.

It must be emphasised that the —Ca, —K and —P effects at this centre were all severe so that the samples should be very suitable for determining these effects on quality. —Mg effects, where they occurred, varied from medium to slight.

Centre VI.

This trial was a repetition of the 1944 experiment at Centre D (1944 Report, p. 192), and manurial details were similar for the two seasons.

Observations made on July 31st, 1945, confirmed those for 1944, viz. low soil pH values resulted in severe —Ca effects to the point of total failure; —K and —N produced severe effects, but there was no visible result from the omission of phosphate.

Pot Experiment. In this experiment, iron, potassium and phosphorus were given to sand cultures in various combinations at the following levels.

Fe :	up to 0.1	5	20	p.p.m.
K :	'0'	135	270	"
P :	'0'	40	70	"

The outstanding effects on growth were that iron and potassium appeared to be mutually beneficial under conditions of deficiency of each other, whereas the action of iron and phosphorus seemed to be antagonistic, a high level of one intensifying deficiency effects of the other.

(b) Cooking Tests.

As in the 1944 experiments, the samples after cooking were rated numerically for external appearance, colour, consistency and flavour, the maximum score under each heading being 5.

*Centre I. Long Ashton.**Plot 12.*

Kerr's Pink. The samples were very wet and broken, but flavour was good and blackening slight; as shown in Table I the only definite blackening was in samples which had received N or N.P. dressings. In the latter, the colour rating was reduced to below 4, the ratings for the other treatments lying between 4 and 5. The manurial treatments produced little change in external appearance or in flesh consistency but flavour was more variable, both phosphate and farmyard manure having an adverse effect. The effect of potash was confined to colour, the only blackening samples being those not receiving potash.

Chloride treatments: The average scores for the samples from plots receiving KCl or NaCl were slightly higher than those from the N.P.K₂SO₄ treatments. The samples were less broken and wet and true blackening was absent. Those receiving NaCl were slightly inferior in colour to those receiving KCl and consistency and flavour were slightly inferior, but the former were less broken and thus better in appearance.

Red King. The general quality scores were similar to those for Kerr's Pink but the colour was superior. Blackening was only seen in samples which had not received K dressings, the ratings for the N. and N.P. plots being between 3 and 4. The addition of K. had little other effect, except a slightly adverse effect on the appearance of the cooked samples.

Chloride treatments: The samples from plots receiving KCl and NaCl were little inferior to the N.P.K₂SO₄ samples and blackening was absent. The NaCl treatments gave slightly lower scores than the KCl treatments and the colour of the samples was not perfect in the former; the consistency of the NaCl samples was, however, firmer.

Majestic. The samples were broken, wet and mealy and blackening, although general, was not intense. The colour scores were between 3.1 and 4.8.

TABLE I.
LONG ASHTON. PLOT 12.
MANURIAL TREATMENTS. AVERAGE SCORES.

Variety	Kerr's Pink			Red King			Majestic		
Treatment	External appearance	Consistency	Flavour	Colour	External appearance	Consistency	Flavour	Colour	External appearance
N	2·1	3·1	4·3	3·8	3·5	3·9	4·3	3·6	2·8
P.K.	3·1	2·9	4·1	4·8	2·3	3·4	4·1	5·0	2·3
N.K.	2·3	3·7	4·2	4·9	2·5	3·4	4·0	5·0	3·1
N.P.	3·0	3·3	3·7	3·5	3·5	3·7	4·0	3·2	3·1
F.Y.M.	2·3	3·2	3·3	4·6	2·7	3·6	4·3	5·0	2·5
N.P.K ₂ SO ₄	2·8	3·0	3·9	4·7	3·3	4·9	4·9	5·0	3·9
N.P.KCl	3·3	4·0	4·2	5·0	3·2	4·2	4·3	4·9	3·5
N.P.NaCl	3·8	3·7	3·8	4·8	3·5	4·5	3·8	4·8	3·7

The samples from plots receiving P. and K. dressings or farmyard manure had the best colour, but were the most broken in appearance. The other quality scores were little affected by treatment.

Chloride treatments: The average scores for samples from plots receiving NaCl were practically the same as those from plots receiving N.P.K₂SO₄, but the KCl treatment gave higher scores for consistency, flavour and colour. No real blackening occurred in the KCl treatments.

Long Ashton.

Plot 17a.

Majestic. The quality of the samples was very similar to that of the Majestic from Plot 12, but there was a greater variation due to treatment (Table II). The samples were wet and broken, except those from plots receiving N.P. dressings which were solid and sticky. Blackening was present in all samples, although scores of 4 were attained by the best samples. The chief effect was produced by the N.P. dressings, and in these samples not only were the tubers inferior in texture but also in flavour. Blackening was greatest in the three treatments not including a potash fertiliser, viz. nil, N.P. and F.Y.M., but was most intense in the N.P. treatment.

TABLE II.
LONG ASHTON. PLOT 17A. MAJESTIC.
MANURIAL TREATMENT. AVERAGE SCORES.

	Treatment	External appearance	Consistency	Flavour	Colour
No Magnesium Sulphate	Nil	3.6	4.0	3.8	2.8
	F.Y.M.	3.6	4.2	4.2	2.9
	N.P.K.	4.0	4.1	3.4	3.6
	P.K.	3.1	3.9	4.1	3.6
	N.K.	3.8	4.5	3.9	3.8
	N.P.	1.6	1.2	2.5	2.1
Magnesium Sulphate	Nil	3.5	3.8	4.0	3.0
	F.Y.M.	3.5	4.5	4.5	3.8
	N.P.K.	3.3	4.0	4.3	4.0
	P.K.	2.8	4.3	4.3	4.0
	N.K.	3.8	4.0	3.0	4.0
	N.P.	2.0	1.5	2.8	3.0

The effect of magnesium sulphate addition was to lessen the differences between fertiliser treatments, but again the only definite adverse effect on the consistency and flavour was produced by the N.P. dressing. The colour in all samples was better following Mg application, but blackening was still considerable in the plots receiving the nil and N.P. treatments.

Centre II. (Majestic).

(a) *Fertiliser Experiment.* The quality of the samples was poor, few reaching a score of 4 under any heading and the averages were generally below 3.

The texture was variable, both solid and broken tubers occurring in the same batch; the solid tubers were close and starchy rather than sticky. In most samples the flavour was rather insipid but was only unpleasant in those with very low scores.

TABLE III.
CENTRE II. FERTILISER EXPT. AVERAGE SCORES FOR TREATMENTS.

Treatment	External appearance	Consistency	Flavour	Colour
N ₀	2.9	2.8	2.3	1.7
N ₁	2.9	2.9	2.4	1.6
N ₂	2.7	2.6	2.1	1.2
P ₀	3.1	2.8	2.7	1.9
P ₁	2.8	2.8	2.2	1.3
P ₂	2.6	2.7	1.9	1.3
K ₀	2.6	2.2	1.6	0.3
K ₁	3.1	2.9	2.5	1.6
K ₂	2.7	3.2	2.7	2.6

Blackening was general and, as shown in Table III, was most severe in plots not receiving K., the average score for these being less than 1. The application of K. improved the colour, the average score for K₁ treatments being 1.6 and for K₂ treatments 2.6. In no case was blackening absent, the highest score for colour being 3. Consistency and flavour were also slightly better at the higher K. levels. Consistency was little different at the three P. levels, but appearance and flavour were adversely affected by the addition of P. The sample with the best all round score was that which had received K. only at the higher rate, the scores being, external appearance and consistency 4—, flavour 3 and colour 3—.

(b) *Claying Experiment.* The general quality was rather better than in the samples from the Fertiliser plots and blackening was less severe. The samples from plots receiving clay were little different in cooking quality from the control samples. The average values for consistency and flavour were slightly higher in the samples from plots receiving clay at the rate of 100 tons per acre, but as shown in Table IV no consistent trend was evident.

TABLE IV.
CENTRE II. CLAYING EXPT. AVERAGE SCORES FOR TREATMENTS.

Tons clay per acre	External appearance	Consistency	Flavour	Colour
Nil	3.1	3.4	2.8	3.2
50	3.1	3.2	2.4	3.1
100	3.2	3.8	3.2	3.1
200	2.6	3.2	2.8	2.9

Centre III. (Majestic).

Claying Experiment. The quality of the samples was very similar to that of those from Centre II. The average ratings for the plots receiving clay were not greatly different from those of the controls (Table V). The addition of clay gave slightly better external appearance and consistency, but the average ratings for flavour and colour were much the same in all treatments, except the 100 tons per acre application, where flavour and colour were slightly lower.

TABLE V.
CENTRE III. CLAYING EXPT. AVERAGE SCORES FOR TREATMENTS.

Tons clay per acre	External appearance	Consistency	Flavour	Colour
Nil	3.4	3.6	3.7	2.9
100	3.7	3.7	3.1	2.3
200	3.9	3.9	3.8	3.4
300	3.8	4.1	3.4	3.2

Centre IV. (Majestic).

The general quality was medium, all samples being starchy but variable in consistency and appearance. Blackening was general and was severe in the worst samples. As shown in Table VI the manurial treatments produced little effect on texture and flavour, the greatest effect being on colour, although even in this case the differences were not large. Samples from plots not receiving K. had the lowest average score (2.2) and those from plots receiving the higher application had the highest average (2.9). No sample had a good colour, the highest score for colour among the samples being 4—.

TABLE VI.
CENTRE IV. AVERAGE SCORES FOR TREATMENTS.

Treatment	External appearance	Consistency	Flavour	Colour
N ₀	3.6	4.0	3.5	2.4
N ₁	3.3	3.7	3.7	2.8
N ₂	3.4	3.8	3.2	2.6
P ₀	3.7	3.9	3.8	2.8
P ₁	3.5	3.9	3.3	2.6
P ₂	3.3	3.7	3.3	2.5
K ₀	3.7	3.9	3.4	2.2
K ₁	3.7	4.1	3.7	2.7
K ₂	3.2	3.5	3.2	2.9

Centre V. (Majestic).

The quality of the samples was poor, the texture being close and pasty, and the individual scores for appearance and flesh consistency were mainly between 2 and 3. Blackening was general and, even when not intense, the cooked tubers were poor in colour and some showed brown discoloration. No sample was free from blackening and the highest score reached in any treatment was 3+.

In the plots receiving no lime, the fertiliser treatments produced no marked change in blackening, nor were the other quality ratings consistently affected. As shown in Table VII, the application of lime gave the greatest improvement in consistency and flavour and some slight improvement in external appearance. The texture and flavour of the samples from plots receiving lime showed no consistent response to the fertiliser treatments, the treated plots showing no improvement over those given lime only.

TABLE VII.
CENTRE V. AVERAGE SCORES AT DIFFERENT LIME LEVELS.

	External appearance	Consistency	Flavour	Colour
No lime	2.4	2.0	1.9	2.2
3 tons ploughed in	3.0	3.1	2.6	2.3
9 tons ploughed in	3.0	3.4	3.2	2.4
9 tons top dressing	2.7	2.6	2.7	2.1

Blackening was more variable following the application of lime. At the lower rate of application (3 tons per acre), blackening was most severe in those plots which had shown K. deficiency symptoms in the haulm, *i.e.* in those receiving N.P., P. and in one nil plot (* in Table VIII). In the other nil plot at the other end of the field, where the symptoms had been those of P. deficiency and not K., the blackening was less severe. At the higher rates of lime application the effect of K. on colour was still noticeable in the plots where

TABLE VIII.
CENTRE V. AVERAGE SCORES FOR FERTILISER TREATMENTS (LIME GIVEN).

Treatment	External appearance	Consistency	Flavour	Colour
Nil	3.6	3.8	3.7	2.5
N.P.K.	3.2	3.2	3.0	2.5
P.K.	3.3	3.3	3.2	2.5
N.K.	2.8	2.9	2.9	2.7
K.	2.1	2.7	2.6	2.9
N.P.	2.8	2.7	1.8	1.7
P.	2.7	3.1	3.0	2.0
Nil*	2.8	2.5	2.5	1.6

the lime had been applied as a top dressing : where the lime had been ploughed in the effect was less clear.

Centre VI. (Majestic).

pH plots. The samples were wet and broken and they had an unpleasant fishy taste. Blackening was present in all samples, the colour scores ranging from 2.5 to 4—. No definite relation between soil pH and cooking quality was observed.

Fertiliser plots. The samples were wet and broken except in the plots which did not receive K. : in these, the samples were solid and close. Blackening was not present in all samples, and, as shown in Table IX, it appeared to be increased by N. and decreased by the application of K. The best colour was found in the P.K. and K. plots where the samples received scores of 5, and as no effect was seen in the field as a result of P. addition, the effect on colour was probably due only to K.

TABLE IX.
CENTRE VI. MANURIAL TREATMENTS. AVERAGE SCORES.

Treatment	External appearance	Consistency	Flavour	Colour
N.P.K.	3.0	3.3	2.5	3.4
N.	2.5	2.0	1.0	2.5
P.K.	2.1	2.5	2.9	5.0
P.	3.0	3.0	3.0	4.5
N.K.	3.0	3.0	1.8	2.6
K.	2.5	3.0	2.5	5.0
N.P.	2.0	2.1	2.0	2.6
Nil	2.0	2.5	3.0	4.0

Long Ashton. (Majestic).

Pot Experiment : Fe, K. and P. levels. The quality of the samples was variable, but no definite blackening was observed. The tubers which had not received K. were immature in appearance and solid in texture. Those not receiving K. but given the high Fe application showed the nearest approach to blackening, but in these the colour score was still 4. All the cooked samples were notable for their marked yellow colour, which was most intense in those which had not received Fe. Of those receiving Fe, the samples showing the most yellow colour were those at the higher P. level. Where P. had not been applied, the colour was least intense. The yellow colour thus appeared to be intensified by P. and decreased by Fe, the effects being antagonistic. The colour appeared mainly due to the presence of carotenoid pigments.

GENERAL DISCUSSION.

Comparison of Results from Centres used in 1944 and 1945.

Long Ashton.

Plot 17a. The main difference between the Majestic samples from this plot in the two seasons was in the texture, which was soapy in 1944 and wet

and broken in 1945. The other quality ratings were similar in the two seasons, but blackening was rather more severe in 1945. Although symptoms of K. deficiency were present in both seasons, the effect on potato quality was more severe in 1945, blackening being more intense in the nil and N.P. plots and consistency more adversely affected. In both seasons the effects of manurial treatment were less marked following the application of Mg.

Centre II.

The general quality of the potatoes from this area was similar in the two seasons, but as in the Long Ashton samples, the main difference was in texture. In 1944 the samples were soapy and sticky, while in 1945, although close in texture, stickiness was absent. The flavour was poor and blackening was severe in both seasons. The only effect of fertiliser application was due to K., which produced some improvement in colour, the effect being more marked in the 1945 season.

Centre V.

In both seasons the potatoes from this trial were of poor quality, being sticky and of poor colour even in the few samples where blackening was not severe. In neither season did the fertiliser treatments affect blackening in the absence of lime. When lime was applied, a slight improvement in colour accompanied the addition of K. The general quality was, however, improved by lime in both seasons. In this latter connection it should be noted that at this centre the soil is very strongly acid and there is a marked deficiency of calcium.

Centre VI.

The results for this centre in the two seasons are not strictly comparable, as Arran Banner and Kerr's Pink were grown in 1944 and Majestic in 1945. In both seasons, however, the chief effects due to fertiliser treatment were those resulting from N. and K. In 1944 blackening was only apparent in samples from the plots receiving N. only; in 1945 blackening was more general but it was again increased by N. and decreased by K. Absence of K. also had an adverse effect on texture in both seasons. In both 1944 and 1945 the field effects of K. deficiency in the absence of the fertilisers were severe and treatment with N. also produced marked effects.

The samples from the acidity plots showed considerable differences in the two seasons. In 1944 the samples of Arran Banner and Kerr's Pink were close and sticky, but in 1945 the Majestic samples were mealy and broken. Blackening was absent in 1944, but was considerable in the 1945 samples.

Varieties and Sites.

Samples of Majestic were received from eight centres and the cooking quality of the samples showed considerable variation. At Long Ashton and at Centres II, III and IV the texture and flavour were fairly good, the scores generally lying between 3 and 4. The samples were starchy and usually lost marks for excessive breakage or closeness of texture. At Centres V and VI the quality was poorer, especially at Centre V where the samples had a sticky texture.

Blackening was present in all series and was very severe at Centres II, IV and V where colour scores of 0 and 1 were recorded. The maximum colour score at these centres was less than 4 in the best samples. At Long Ashton

and at Centres III and VI blackening was less severe, the lowest score being about 2 and the best scores lying between 4 and 5. True blackening was absent in the pot experiments at Long Ashton.

The only other varieties tested were Kerr's Pink and Red King on plot 12 at Long Ashton. Both varieties were very mealy and broken after cooking, and the general quality was not very different from that of the Majestic samples from the same plot. The incidence of blackening was very similar in the three varieties, but the best samples of Kerr's Pink and Red King were slightly superior in colour to the best Majestic samples.

The effect of site on the quality of Majestic is shown by the average colour scores for the different manurial treatments at the Centres (Table X).

TABLE X.
BLACKENING AT DIFFERENT SITES (MAJESTIC).

Treatment	Nil	N.P.K.	P.K.	N.K.	N.P.	N.	P.	K.
Long Ashton 12	—	3.8	4.8	3.9	3.1	3.7	—	—
„ „ 17a	2.8	3.6	3.6	3.8	2.1	—	—	—
Centre II	1.0	1.8	2.3	2.3	0	1.0	0	2.4
Centre IV	3.0	2.8	2.8	3.1	2.6	1.9	1.0	2.8
Centre V	1.8	2.5	2.8	2.5	1.5	—	1.5	3.3
Centre VI	4.0	3.4	5.0	2.6	2.6	2.5	4.5	5.0

The sites fall roughly into two groups, in one group, Long Ashton and Centre VI, the average scores for the different treatments lie within the range of 2—5, and in the other, Centres II, IV and V, the corresponding ranges are between 1 and about 3. As was found in the 1944 trial, the degree of blackening after cooking was determined largely by the site, and although some of the manurial treatments decreased the blackening (K. effects), it was only possible to improve the colour to a limited extent.

The other quality characters such as flavour and consistency appear to be influenced not only by site effects and by manurial treatments, but also by seasonal changes. Although deleterious effects have been produced by adverse fertiliser treatments or by actual deficiency conditions, the character of the potatoes has been found to differ under identical treatments in different seasons, *e.g.* the texture has, in general, been found more mealy in the 1945 season than in 1944, the sticky consistency encountered in 1944 being virtually absent in the later season.

Manurial Treatments.

As in 1944, where definite deficiencies of elements occurred, the addition of the corresponding fertiliser produced beneficial effects on cooking quality, although as indicated above, the response was limited by other factors such as site effects. At Long Ashton and at Centres II, IV, V and VI symptoms of K. deficiency were severe and the addition of K. fertilisers at these sites improved the quality of the potatoes. The main improvement was in the colour, texture and flavour being less consistently affected.

At Centre V the primary deficiency was Ca, and where this was not corrected little response was produced by fertiliser treatments. When Ca

status was rendered satisfactory by liming, then deficiencies of K., P and Mg appeared. The plots showing K. deficiency showed a quality response to fertilisers containing K., blackening being most severe in the N.P. and P. treatments; on one side of the plots where the main deficiency was of P. rather than of K. the tubers showed less intense blackening. At Centre VI., on the plots of satisfactory Ca status, blackening was decreased by the application of K. but was increased by N., and was considerable in all treatments containing that element. At Long Ashton (17*a*) and at Centres II and VI the application of K. also improved texture and external appearance. At Centres II and III these latter characters were adversely affected by fertilisers containing P.

In the 1945 series of tests the effect of K. on blackening has been more consistently observed than in the 1944 season, *e.g.* at Centre V where K. deficiency was severe in both seasons, the application of K. had a more significant effect on colour in the 1945 season.

The application of K. in the form of KCl in the Long Ashton trial (Plot 12) produced symptoms of chloride damage in the haulm, and this was also observed in the NaCl plots but no adverse effects on yield resulted from either of the treatments. The general quality was not inferior to that of the samples from other comparable manurial treatments where K_2SO_4 was used, and the chloride effects had apparently little influence on the quality of the crop. The samples from the KCl plots were slightly better than those receiving the NaCl treatments in flavour, colour and consistency, but the former were more broken and thus scored less for appearance. Where chloride treatment was given true blackening only appeared in the Majestic samples and was only appreciable in tubers from the NaCl plots.

CONCLUSIONS.

The present results largely confirm those obtained in the previous season, *viz.* that potato quality is more affected by the general character of the site than by fertiliser treatment. Although it has been possible to raise the general level of quality by treatments designed to overcome severe deficiencies, the improvement effected has been limited by factors other than fertiliser requirements, apparently inherent in the general site conditions.

Where it has been possible to compare samples from the same sites in the two seasons, the most striking difference has been found in the texture of the samples, which was better, although excessively mealy, in the 1945 season. In the variety Majestic, grown on the same site at Long Ashton, the extent of blackening was very similar in the two seasons.

As in 1944, Majestic showed more tendency to blacken than did Kerr's Pink, but the difference between the two varieties was rather less noticeable in 1945. In general quality, Red King was superior to both Kerr's Pink and Majestic. Of these varieties Kerr's Pink was inferior in appearance and consistency, many samples being excessively broken and wet, whilst Majestic was poorest in colour, blackening being more serious than in the other two varieties.

SUMMARY.

1. Further studies have been carried out on factors affecting the cooking quality of potatoes, particular attention being paid to the incidence of blackening on boiling.

2. Samples from five different centres were examined, three of the sites being among those included in the 1944 trials. The sites comprised a

variety of soil types providing examples of deficiencies of N., P., K., Ca and Mg. The effects of manurial treatments on three varieties were tested and the effect of applying clay to Fen soils was also studied with the variety Majestic.

3. The main conclusion of the 1944 trial was confirmed, viz. that the quality of the potatoes is largely determined by characteristics inherent in the site; the application of manures produced only a limited improvement where quality was initially poor. Seasonal effects were also noted, samples from particular sites in 1945 being much more mealy in texture than from the same sites in 1944.

4. Within the limits determined by the site, the correction of definite deficiencies gave some improvement in general quality. The correction of K. deficiency was associated with an improvement in the colour of the cooked samples, the effect being more noticeable than in the previous season. Where P. deficiency was observed, phosphate manuring did not affect the colour.

5. Under conditions of acute Ca deficiency manurial treatment gave no improvement in quality, but when the Ca status was improved, secondary deficiencies appeared and quality was affected by manurial treatment.

6. The application of KCl and NaCl was found to give rise to symptoms of chloride toxicity in the haulm, but yields and general quality were not adversely affected.

7. In sand culture, the application of P., K. and Fe at different levels did not cause blackening in Majestic, but low concentrations of Fe combined with high concentrations of P. produced a yellow colour in the cooked samples.

8. The varieties Kerr's Pink, Red King and Majestic, grown on one site where blackening was not severe, were not greatly different in cooking quality. The Majestic samples were, however, slightly inferior in colour.

Thanks are due to the following for co-operating in the field tests and supplying samples of tubers for cooking: Mr. W. Morley Davies, Harper Adams Agricultural College, Mr. F. Hanley, School of Agriculture, Cambridge, and Mr. K. M. Pearman, of the Gloucestershire W.A.E.C.

Thanks are also due to Miss M. Sturdy for assistance in the cooking tests and to Miss J. D. Bryan and Mrs. J. Tolhurst for their help in preparing the samples.

REFERENCE.

POLLARD, A., KIESER, M. E., CRANG, B. A., WALLACE, T. *Ann. Rept. Long Ashton Res. Stn.*, 1944, pp. 184—199.

THE CONTROL OF BLACKENING OF BOILED POTATOES.

By ALICE CRANG, DILYS JAMES and MARGARET STURDY.

INTRODUCTION.

The following investigation was carried out to find whether the blackening known to occur with many potatoes when boiled by the usual methods could be overcome by the use of acids in the soaking or cooking water. Such methods have already been recommended for the treatment of potatoes before dehydration (1).

The potatoes used in all these experiments were selected from consignments which had already been tested for boiling quality (2) and had been

awarded low scores for colour, indicating considerable blackening in the cooked tubers.

EXPERIMENTAL.

The effect of acids and sulphur dioxide in the water has been tested in the following stages of the treatment of the potatoes :—

- (1) Soaking the peeled potatoes overnight.
- (2) Blanching the potatoes before peeling.
- (3) Blanching the peeled potatoes.
- (4) Boiling.

The effects of hard, softened and rain water ; steaming ; and the use of aluminium, enamel and iron pans have also been noted.

Method of Sampling. In all the tests on peeled potatoes, they were cut into halves or quarters longitudinally and divided amongst the treatments to eliminate any error due to variations between the tubers, or between the two ends of individual tubers.

For testing the cooked potatoes, samples from several representative potatoes were taken.

1. Soaking the Potatoes.

The peeled potatoes were soaked overnight in water acidified with acetic acid to a pH of 3.4. After cooking, these showed considerable blackening and little improvement over the controls soaked overnight in plain water.

Other potatoes were soaked in a dilute solution of sulphurous acid, and although this soaking gave a whiter potato before cooking, blackening occurred after, and the treatment was not so effective as some of those tested later.

2. Blanching the Potatoes before Peeling.

One method recommended for treating potatoes for dehydration is to boil them for 7 minutes in water, peel them while hot, then blanch in acidified water (1).

This heat treatment before peeling the potatoes gave very poor results. The potatoes were difficult to peel by hand, as the skins were slippery, and some surface blackening occurred during peeling. The temperature in the centre of a small potato after 7 minutes boiling was 67°C. and that of a large one only 43°C., temperatures insufficient to destroy any enzymes which might accelerate discolouration. In each treatment the potatoes which had been partly cooked before peeling were poorer in colour than those which were peeled raw. It was decided not to continue this treatment.

3. Blanching the Peeled Potatoes.

The potatoes were peeled without previous treatment, blanched for 5 minutes in boiling solutions of sulphurous acid or orthophosphoric acid, both at pH 4, then cold dipped, and boiled until cooked in plain water with the usual amount of salt. (See Table I.)

Both treatments gave some improvement in colour over the potatoes boiled in plain water.

Further tests were made keeping the pH of the blanching water to approximately 4 by additions of acid during the blanching period. This treatment gave no noticeable improvement over the previous one, the potatoes being slightly better than the control, but still showing distinct blackening.

TABLE I.

CHANGES IN pH OF THE SOLUTIONS AND POTATOES DURING COOKING.

Treatment	pH of Blanching Water		pH of Cooking Water		pH of Potatoes			Marks awarded for Colour (Max. 5)
	Before	After	Before	After	Raw	Blanched	Cooked	
Blanched 5 min. in O.P.A.*	4.04	5.69	7.50	7.68	5.71	5.87	5.97	3—
Cooked in water								
„ (sliced potatoes used)	4.04	5.73	7.44	8.32	5.71	—	6.20	3—
Blanched 5 min. in $\text{SO}_2^\dagger$, cooked in water	3.97	5.67	7.50	7.92	5.71	5.86	5.96	2+
„ (sliced potatoes used)	3.97	5.70	7.44	8.34	5.71	—	6.06	3+
Blanched and cooked in water	7.50	8.84	7.50	7.95	5.71	5.84	5.99	2
Boiled 7 mins. before peeling, blanched in O.P.A. Cooked in water	4.04	5.69	7.50	7.81	5.71	5.74	6.06	0

* O.P.A. = 0.2 ml. orthophosphoric acid per litre.

† SO_2 = 1.1 ml. sulphurous acid per litre.

4. Boiling the Potatoes.

The effect of having acid present in the water during the whole of the cooking period was then studied, using vinegar with 5% acetic acid content; orthophosphoric acid; sulphurous acid; and sodium metabisulphite (Campden Fruit Preserving Tablets), the last with or without the addition of acid.

Orthophosphoric acid had no merits over acetic acid, either in the final colour or in the flavour of the potatoes, when sufficient quantities were employed to bring the cooking water to the same pH value. As acetic acid, in the form of vinegar, would generally be available, orthophosphoric acid was not used in any of the final tests.

Sulphurous acid proved more effective than acetic acid in preventing the blackening of the cooked tubers but a disadvantage is the sulphur dioxide left in the potato. As sodium metabisulphite is available in a convenient form (as Campden Fruit Preserving Tablets), these were tried in place of sulphurous acid. As expected it was not effective alone, but was just as effective as sulphurous acid when used together with acetic acid, which would liberate the sulphur dioxide during the cooking period.

Various concentrations of acetic acid and sulphur dioxide were tried, and the best result for colour, without having a serious quantity of sulphur dioxide left in the potato, was obtained using 20 ml. vinegar (5% acetic acid content) and 1 Campden Fruit Preserving Tablet (about $\frac{1}{2}$ gm. sodium metabisulphite) to each litre of water used for cooking the potatoes. Typical changes in pH value and SO_2 content of the cooking water and potatoes are given in Table II. In each case the amounts used were 1 dessertspoonful of salt and 1 litre of water.

TABLE II.

Treatment	Water before cooking		Water after cooking		Cooked Potato		Colour (Max. 5)
	pH	SO ₂ p.p.m.	pH	SO ₂ p.p.m.	pH	SO ₂ p.p.m.	
Softened Tap Water							
Cooked with OP.A.	4.24	—	5.43	—	5.73	—	3 —
" " SO ₂	3.68	—	5.62	104	5.74	64	3 +
Control	7.44	—	—	—	5.91	—	3 —
Rain Water							
A. Control	6.00	—	5.82	—	5.89	—	Grey-black
B. 2.25 ml. 5% SO ₂	3.16	128	5.44	134	5.98	27	Some blackening
C. 4.5 " "	2.81	224	5.28	147	5.82	42	Slight " "
D. 6.75 " "	2.62	305	5.25	173	5.79	47	" " "
E. 1 NaMS tablet† + 6 ml. Vinegar	3.83	144	5.03	147	5.87	20	" " "
F. 1 " " + 12 " "	3.68	305	4.77	205	5.62	39	" " "
G. 1½ " " + 18 " "	—	320	4.78	211	5.54	70	Very " "
Hard Water							
H. 1 NaMS tablet + 12 ml. Vinegar	4.59	284	5.58	264	5.76	120	Very " "
I. 1 " " + 16 " "	4.43	256	5.27	264	5.70	106	" " "
J. 1 " " + 20 " "	4.35	284	5.10	224	5.55	77	Best for colour
K. 16 ml. Vinegar	4.52	—	5.24	—	5.64	—	Slight blackening
L. 20 " "	4.37	—	5.06	—	5.43	—	" " "

† NaMS = Sodium metabisulphite.

In the samples tested, severe blackening occurred whether the potatoes were cooked in softened water, rain water or in hard water, but the most serious in the last-named.

Flavour. The sulphur dioxide flavour was very noticeable when present in quantities greater than 100 p.p.m. in the cooked potatoes, but was scarcely noticeable in concentrations up to 80 p.p.m., especially when acetic acid was also present.

Consistency. The potatoes cooked in acid and sulphur dioxide solutions generally tended to be less floury in consistency than the controls.

Further Experiments.

To confirm the results obtained using acetic acid and sulphur dioxide in the cooking water, tests were repeated the following season, again using potatoes which blackened severely when cooked in the normal way. The results are given in Table III, with the marks awarded for colour and flavour.

In order to facilitate measurements in the home, 1 quart of water was used instead of 1 litre, so that the acid and sulphur dioxide concentrations were slightly lower than in the previous tests. Hard water was used in each case, and 1 dessertspoonful of salt added to the cooking water.

TABLE III.

Treatment	pH of Cooking Water		pH Cooked Potato	Colour (Max. 5)	Flavour (Max. 5)
	Before	After			
(a) Control	7.26	7.82	5.90	2	4
(b) 5 ml. 5% SO ₂	5.45	5.80	5.90	3	2
(c) 8.5 ml. Vinegar	5.45	5.70	5.82	3 —	4 —
(d) 20 ml. " "	4.50	4.90	5.66	3 +	3½
(e) 20 ml. Vinegar + 1 NaMS-tablet	4.55	5.08	5.64	4 —	3½
(f) 1 NaMS tablet	6.72	7.03	6.10	2 +	2

These results confirm that most of the blackening can be controlled by the addition of sodium metabisulphite and vinegar, and to a lesser extent by the addition of vinegar alone to the cooking water, but this is at the cost of some loss of flavour. Sulphur dioxide was very noticeable in (b) and (f) but only detected in (e) by people who were experienced tasters; others considered the flavour was unobjectionable, but not such a good potato flavour as the control.

Sulphur Dioxide Content. The sulphur dioxide content of the freshly boiled potatoes when treated by method (e) Table III, varied from 32 to 35 p.p.m. in boiling tests on two different varieties of potato. In each case approximately 2 lb. of potatoes were cooked in a quart of solution, and the saucepans covered in the usual way during cooking.

The Effect of Steaming. The addition of acetic acid and sulphur dioxide to the water used in steaming the potatoes was not effective in preventing blackening even when four times the quantities used in boiling the potatoes was added.

The Effect of the Pans. Unchipped enamel, chipped enamel, iron and aluminium pans were used to see whether any of these had any adverse effect when acid and sulphur dioxide was added to the boiling water just before the potatoes were put in. Under these conditions, there was no noticeable difference in the potatoes due to the type of pan used.

DISCUSSION.

The blackening which occurs in certain potatoes when boiled in the usual way can be controlled to some extent by the addition of acid to the cooking water, as noted by other workers (1), (3). The control, however, was found to be more effective when sulphur dioxide was used in the cooking water. The best results were obtained using sodium metabisulphite and acetic acid, in such a proportion that about 35 p.p.m. of sulphur dioxide was left in the freshly cooked potato; if sulphurous acid were used alone, the quantity necessary to control the blackening was too great for the resulting potato to be palatable.

When the potatoes were arranged in order of pH in the cooked tubers, there was a corresponding grading for colour, there being severe blackening in tubers with pH of 6.19 to 5.98, less severe blackening with those of pH range from 5.98 to 5.76 while those with pH 5.70 to 5.43 were of a reasonably good colour. The above results were obtained irrespective of the kind of acid used in the cooking water.

As a point of interest the pH was compared on the stem and rose ends of an individual cooked tuber. The stem end, which had blackened severely, was at pH 6.35 and the rose end, a good potato colour, was at pH 5.91.

Soaking the potatoes, or pre-cooking them in acid solutions followed by boiling them in water, was not nearly so effective in preventing blackening as boiling them for the whole cooking period with acids. The addition of acetic acid and sulphur dioxide was not effective in ordinary concentrations when the potatoes were steamed.

The control of blackening could only be attained at the expense of some loss of flavour and flouriness in the potatoes. One tablespoonful of vinegar added per quart of water used for cooking the potatoes improved the colour, but did not control the blackening altogether. The flavour of these potatoes was generally described as rather acid but not unpleasant, and the consistency was rather solid compared with the control.

A good control of blackening was obtained by the addition of 1 Campden Fruit Preserving Tablet and 1 tablespoonful of vinegar per quart of water. Sulphur dioxide was detected in these potatoes by a few experienced tasters but the tubers were not considered as acid as those cooked with vinegar alone. Most tasters described them as not unpleasant, but lacking true potato flavour when compared with the control, and considered that these potatoes would be quite acceptable when taken as part of a meal. The consistency was similar to the potatoes cooked with vinegar.

Whether it is desirable to recommend the addition of traces of sulphur dioxide to a food consumed in such large quantities as potatoes is a matter of opinion. At the present time there are no regulations limiting the amount of sulphur dioxide allowed in freshly cooked potatoes, but up to 500 p.p.m. is permitted in dehydrated potatoes. The quantity found in the potatoes cooked by the method given above was 35 p.p.m. It seems that this treatment should only be used, if at all, when potatoes are in very short supply and of such a poor colour when cooked in the normal way that they would not be generally acceptable.

SUMMARY.

1. The colour of potatoes which blacken when boiled in the usual way can be improved by the addition of 1 tablespoonful of vinegar to each quart of the cooking water.

2. The blackening can be controlled almost completely by the addition of $\frac{1}{2}$ gm. sodium metabisulphite (1 Campden Fruit Preserving Tablet) together with 1 tablespoonful of vinegar per quart of water. The cooked potatoes will then contain about 35 p.p.m. of sulphur dioxide.

3. There is some loss of true potato flavour and of flouriness in consistency when either of these treatments is used.

Acknowledgments.

Our thanks are due to Professor T. Wallace, Dr. A. Pollard and Miss M. Kieser for co-operation in this work.

REFERENCES.

- (1) SMITH, ORA, and KELLY, W. C. Paper 265, *Dept. of Veg. Crops, Cornell Univ., Ithaca, U.S.A.*
- (2) POLLARD, A., KIESER, M. E., CRANG, A., and WALLACE, T. *Ann. Rept., Long Ashton Research Station, 1944, 184.*
- (3) WAGER, H. G. *Biochem. J.*, 39, 485.

REPORT ON ADVISORY WORK, 1944-45.

In 1945 the war phase of agricultural advisory work ended and a period of profound administrative changes began. The principle of a National Agricultural Advisory Service was accepted by the Government and the first steps in setting up this service were taken.

In agricultural economics, an alteration in the status of the Adviser and his assistants was made in September 1945. The Bristol and Seale Hayne staffs were detached from their former departments and made part of a Provincial Agricultural Economics unit under the direction of the Economics Department of Bristol University.

The total of advisory letters sent rose from 8,262 in 1943-44 to 9,933 in 1944-45. The summary below gives the county totals with comparable figures from 1940 onwards.

ENQUIRIES SUBMITTED TO THE DEPARTMENT, 1940—1945.

	Year ended September 30th.					
	1940	1941	1942	1943	1944	1945
Gloucester (including Bristol) ..	1965	2491	2676	2908	2231	2711
Hereford	182	196	729	771	438	579
Somerset	1403	1479	2039	2491	2076	2394
Wiltshire	970	1410	1372	1691	1389	1214
Worcester	656	1010	1506	1491	699	659
Other Areas	2686	1776	2030	1528	1429	2376
Totals	7862	8362	10352	10880	8262	9933

The principal increases are shown by Agricultural Chemistry (+ 670), Veterinary Science (+ 1027) and Economic Entomology (+ 246).

In the advisory work on Agricultural Chemistry 9,450 soil samples were examined, the majority for W.A.E.C. officers requiring information on manurial requirements. Examinations of samples of lime were made for the Ministry's Agricultural Lime Division to secure that suppliers were maintaining a satisfactory standard.

The Adviser in Dairy Bacteriology reports that the development of the National Milk Testing and Advisory Scheme has increased the attention given to the bacteriological quality of milk, thus adding to the volume of advisory work. Routine milk sampling is now being transferred to the area laboratories set up under the National Scheme.

In Agricultural Economics, preparations for obtaining representative accounts by methods of random sampling were made at farmers' meetings in Hereford and Worcestershire. The National Farm Survey was continued and more data were obtained for the Enterprise Costs and full costings schemes. Milk Production is being costed on 62 farms in the Province.

The Veterinary Investigation Officer lists over 47,000 specimens received for examination, of which 38,629 were poultry blood samples. Among the commoner poultry diseases were *Salmonella* infections and lymphomatosis. In cattle, the major subjects of requests from practitioners deal with problems of sterility.

In advisory work in Pomology, two of the principal topics were the use of growth-promoting substances and the establishment of blackcurrant plantations. Visitors to the Station numbered over 2,000, the outstanding party being the 250 members of the Horticultural Education Association.

In Horticultural Chemistry the demands for information were mainly concerned with crop failures and manurial values. Many enquiries dealt with magnesium deficiency in glasshouse tomatoes and methods of control of this trouble. Demonstrations of the sand culture and tissue test work at Long Ashton have been given to many hundreds of appreciative visitors from home and overseas.

The feature of the fruit section of the advisory work in Entomology was the help provided to the county W.A.E.C.'s in developing and maintaining contract spraying of fruit trees. Courses of instruction were given at Long Ashton in the technique of spraying and in the maintenance of spray machinery. Visits were made to many of the counties to supervise the progress of spraying operations in the field. In entomological work on agricultural problems, the provision of increased assistant staff made possible a considerable extension of local investigations and advisory work.

In Economic Mycology, the Adviser notes that there is abundant evidence that soil-borne diseases are on the increase, particularly in areas of concentrated vegetable culture. Surveys of root rots of tomatoes, peas and clover, and of onion and cereal diseases have been carried out.

The demand for courses in Domestic Preservation is still much greater than can be met by the Department. The courses in 1945 were attended by a total of 99, the maximum that could be accommodated. Instruction was also given in Devon at one-day schools for the training of local show judges.

In Cider-making many enquiries have dealt with fermentation and storage vessels, particularly those constructed in reinforced concrete. The frequent requests concerning ropiness and oiliness of ciders indicate the widespread and apparently increasing prevalence of these disorders in recent years.

Staff Changes.

Agriculture and Agricultural Chemistry.

Appointment :—Mrs. B. L. Rawcliffe, B.Sc., as Field Assistant.

Resignations :—Mr. R. Stewart, B.Sc., Ph.D., Adviser in Agricultural Chemistry ; Miss M. Bottomley, B.Sc., Surveyor of Fertiliser Practice.

Dairy Bacteriology. (National Milk Testing and Advisory Scheme).

Resignations :—Miss B. Glason, B.Sc., N.D.D., Area Supervisor ; Mrs. M. Hellier, B.Sc., Area Supervisor.

Agricultural Economics.

Appointments :—Mr. M. M. Carrie, B.A. (Agric.), Scientific Assistant ; Mr. G. L. David, Technical Assistant.

Resignations :—Mr. J. E. Blundell, M.Com., Assistant to Economist ; Mr. V. M. Wadsworth, B.Sc., Technical Assistant ; Mr. M. M. Carrie, B.A. (Agric.), Scientific Assistant ; Mrs. D. S. L. Powell, Temporary Assistant ; Mrs. K. C. Sherwood, National Farm Survey.

Veterinary Science.

Appointment :—Mr. A. D. Osborne, M.R.C.V.S., as Assistant Veterinary Investigation Officer.

Resignation :—Mr. B. Rimmer, M.R.C.V.S., Assistant Veterinary Investigation Officer.

Economic Entomology. (Wireworm Survey).

Appointment :—Mrs. S. M. Wadsworth as Junior Scientific Assistant.

Resignations :—Miss J. Brassington, Miss E. O. Murphy and Miss C. M. Harrison, Junior Scientific Assistants.

Economic Mycology.

Appointment :—Miss M. C. D. Munro, B.Sc., Ph.D., as Senior Scientific Assistant in Mycology ; Mr. H. E. Croxall, Ph.D., as Advisory Officer, Evesham Field Laboratory.

Domestic Preservation.

Appointment :—Miss M. Sturdy, B.Sc., as Assistant Instructress.

Resignation :—Mrs. M. Croxall, Dip.Hort., Assistant Instructress.

Cider Instruction.

Resignation :—Mr. P. T. H. Pickford, Dip.Hort., Cider Instructor.

PUBLICATIONS, 1945.

LONG ASHTON RESEARCH STATION.

- HEWITT, E. J.
Marsh spot in beans. *Nature*, CLV, 22.
- MARSH, R. W.
Mycological contacts (Presidential address to the British Mycological Society). *Trans. Brit. Mycol. Soc.*, XXVIII, 1.
- MARTIN, H.
The ovidical properties of the tar and petroleum oils. *Verh. 7 int. Kongr. Ent. Berlin* 1938, IV, 3020.
The physicochemical factors affecting spray deposition and spray retention. *Verh. 7 int. Kongr. Ent. Berlin* 1938, IV, 3013.
- MILES, H. W.
Wireworms and wartime farming. *Agriculture*, LI, 462.
- MILES, H. W. and MILES, MARY.
Potato root eelworm in Worcestershire. *Worcs. C.C. Agric. Chron.*, XIII, 129.
- MILES, MARY.
Wireworms and wartime agriculture. *New Biology*, I, 86 (Penguin Books, London).
- OGILVIE, I.
Seed infections as a cause of outbreaks of *Didymella* stem rot of tomato. *Gard. Chron.*, CXVIII, 71.
- OSMOND, D. A.
Soils suitable for fruitgrowing. *Worcs. C.C. Agric. Chron.*, XIII, 83.
- SWARBRICK, T.
Parthenocarpic production of tomato fruits. *Nature*, CLVI, 300.
Use of growth-promoting substances in the prevention of apple drop following frost. *Nature*, CLVI, 691.
- WAIN, R. L. and WILKINSON, E. H.
Studies upon the copper fungicides. VII. The solution of copper from dressings on the pea seed. *Ann. Appl. Biol.*, XXXII, 240.
- WALLACE, T.
The maintenance of soil fertility. *Worcs. C.C. Agric. Chron.*, XIII, 17.
Some aspects of mineral deficiencies in farm crops. *Agric. Progress*, XX, 20.
Diagnosis of mineral deficiencies in crop plants. *Nature*, CLV, 444.
Manuring fruit crops in wartime. *Growmore Bull.* 4 (1945 revision). H.M.S.O., London.
- WALLACE, T., HEWITT, E. J. and NICHOLAS, D. J. D.
Determination of factors injurious to plants in acid soils. *Nature*, CLVI, 778.

BERKELEY SQUARE ADVISORY CENTRE.

- BROUGHTON, R. C.
Comparative tables for the Cotswold group; cropping year 1943. *Bristol Univ. Notes on Farm Economics* (n.s.), 11, Jan. 1945.
- BROUGHTON, R. C. and PONTIN, J. M.
Comparative tables for Worcestershire and N. Gloucestershire; cropping year 1943. *Ibid.*, 12, Jan. 1945.
- BROUGHTON, R. C. and CAUDWELL, G. H.
Comparative tables for Bristol group; cropping year 1943. *Ibid.*, 13, Jan. 1945.
- CAUDWELL, G. H.
Comparative tables for mid-Gloucestershire; cropping year 1943. *Ibid.*, 14, Feb. 1945.
Comparative tables for Herefordshire; cropping year 1943. *Ibid.*, 15, Feb. 1945.
- DAWE, C. V.
Cost of production of corn crops, 1943. *Ibid.*, 17, Feb. 1945.
Cost of production of root and fodder crops, 1943. *Ibid.*, 18, June 1945.
A farmer's guide to cost accounting. *Ibid.*, 20, May 1945.
Summer milk production in the south-west. *Farm Economist*, IV, 124.
- EGDELL, J. W. and BIRD, ELIZABETH R.
The effect of thermophilic organisms in holder-pasteurised milk on the reduction of Methylene Blue dye. *Dairy Industries*, X, 266.

HEWETT, L. J. and WADSWORTH, V. M.

Summary report of farms in the Bristol Province, 1943. *Bristol Univ. Notes on Farm Economics* (n.s.), 16, March 1945.

CAMPDEN RESEARCH STATION.

ADAM, W. B. and DICKINSON, D.

Fruit gumming of Victoria plums—progress report.V. *Campden Ann. Rept.*, 1944, p. 12.

ADAM, W. B.

Vitamin C content of canned potatoes and canned peas. *Ibid.*, p. 20.

DICKINSON, D.

The internal corrosion of cans—progress report II. *Ibid.*, p. 28.

ADAM, W. B.

Corrosion and hydrogen swells in canned vegetables. *Ibid.*, p. 37.

DICKINSON, D.

The determination of tin in canned foods. *Ibid.*, p. 46.

DICKINSON, D.

Determination of hydrogen sulphide in foods and waters. *Analyst*, LXX, 5.

DICKINSON, D.

Observations of the properties and purification of waste waters from fruit and vegetable canneries. *J. & Proc. Inst. Sewage Purif.*, February 1945.

HIRST, F. and ADAM, W. B.

The processing and laboratory examination of canned potatoes. *Chemistry and Industry*, LXIV, 91.

ADAM, W. B. and DICKINSON, D.

The substitution of blackplate for tinplate in cans for fruits and vegetables. *Iron and Steel Inst.*, Aug. 1945.

